United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-161**

The 1988 Symposium on Systems Analysis in Forest Resources

March 29 to April 1, 1988

Asilomar Conference Center
Pacific Grove, California

Preface

In 1975, the Society of American Foresters' Systems Analysis Working Group sponsored a Working Group Symposium on Systems Analysis in Forest Resources Management. This meeting was held in Athens, George at the University of Georgia. In 1985, after a hiatus of 10 years, a second symposium was held at the same location. During this meeting, it was agreed to start holding those meetings every three years.

These proceedings contain the papers of the third such symposium, held in Asilomar, California in the spring of 1988. As with the first two meetings, a diverse and interesting group of papers was presented. General topic areas include land management planning, artificial intelligence, multicriteria optimization and fuzzy systems, regional timber supply analyses, stand level optimizations, and timber harvest scheduling.

In this publication, papers are arranged in sections corresponding to the sessions of the symposium. Papers presented in the poster session appear at the end.

We thank the keynote speakers, Mr. Jeff M. Sirmon and Mr. Robert Ewing, and to Dr. Stuart E. Dreyfus and Dr. Michael H. Rothkopf who presented excellent tutorials on artificial neural networks and oral vesus sealed bidding systems for selling resources.

As always, the participants are the heart of this type of meeting. We thank them for their involvement, and for submitting their papers in electronic form to help speed publication. The opinions expressed in these proceedings are the authors' own, and do not necessarily reflect those of the USDA Forest Service or the other sponsoring organizations.

Finally, thanks are also due the sponsors for their support.

We look forward to the next meeting, now scheduled for 1991.

Brian M. Kent
Larry S. Davis

USDA Forest Service
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June 1988

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Brian M. Kent and Larry S. Davis
technical coordinators

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Integrated Planning as Negotiation: A California Perspective on Forest Planning Analysis Requirements

Robert A. Ewing[1]

Abstract.--Forest planning in California is challenged by a dynamic social environment. In response, California Department of Forestry and Fire Protection and the University of California, Berkeley, have initiated a project to better coordinate federal-state forest planning. The project is based on the concept of planning as negotiation. This involves a focus on collaborative approaches to resolving policy disputes, development of options for mutual gain, and identification of strategies for institutional adjustment. The primary use of systems analysis is to provide a quantitative representation of options for mutual gain.

Forest planning in California is a complex enterprise involving a variety of agencies, levels of government, and interest groups. Since 1974, the USDA Forest Service has been attempting to implement its responsibilities under the Forest and Rangeland Renewable Resources Planning Act and the National Forest Management Act (NFMA) relative to national, state, and local needs. To date, the agency has published several national assessment and program documents that bear, to some degree, on management issues in California. A guide for the Pacific Southwest Region has been published, and each of California's 18 national forests has published a plan that is either final or in some stage of final review. On the state side, the California Department of Forestry and Fire Protection has been mandated to produce a periodic forest and rangeland assessment and to work with the California Board of Forestry to write an accompanying policy statement. These two reports currently are being completed.

Attempts have been made to coordinate these various planning and assessment efforts, but they have been only marginally successful. Effective integration of planning programs in California is more a goal than a reality.

This said, the Department of Forestry and Fire Protection's Forest and Rangeland Resources Assessment Program (FRRAP), in cooperation with the University of California, Berkeley, is attempting to develop a process to better coordinate federal-state forest planning. The Washington and Regional offices of the Forest Service have been invited to join the project.

This paper presents the broad outlines of this process. My purpose is threefold. First, I would like to provide some feel for the contemporary dimensions of forest planning in California. Second, I want to introduce the concept of planning as negotiation. Third, I will attempt to define some general requirements for systems analysis given an integrative approach to planning.

For lack of better term, I will define our approach to planning and systems analysis as a process of large-scale, multi-party negotiation. The goal of planning as negotiation is: (1) to define a collaborative approach for resolving forest policy disputes; (2) to identify planning results that produce benefits for mutual gain; (3) to recommend necessary institutional adjustments; and (4) to create the analytical infrastructure to support all this.

While both Forest Service and state planning are at least ostensively directed to such goals, the record of accomplishment is not good. In addition, the development of operations research tools generally has not been thought of in these terms. The point of this paper is to suggest that there is a need to design a planning and analysis process that produces negotiated agreements on the future direction of forestry, at least in California.

Dimensions of Planning in California

The need for a new approach to forest planning in this state stems from the dynamic environment that forest planners face here. For various reasons, the progress made in completing

[1]*Program Manager, Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection.*

California national forest plans is behind most other regions. Our work in FRRAP also has taken a greater investment in time and effort than originally anticipated. The scope of the planning problem, the changing importance of the resource base and its uses, and the wide variety of groups concerned with resource policy require a substantial, sophisticated, and anticipatory approach to planning. We are only now beginning to come to grips with these realities.

While change occurs in all parts of the U.S., the California experience is unusual. For more than a century, California has experienced a population explosion of unparalleled proportion (Bradshaw 1986). In the years since statehood, the number of Californians has doubled on average every 20 years. This represents the fastest long-term population growth of any industrialized region in the world. In 1900, there were 2 million Californians. Today, there are nearly 27 million. Since 1957, when we passed New York, California has been the most populous state in the nation.

This breakneck pace is not projected to continue. The population is not expected to double again until after 2050. Still, population growth and ethnic diversification will remain a dominant force for change. Projections for the year 2000 indicate a population of 31 million, and by 2020, 37 million (California Department of Finance 1986). Thus, in the next 12 years, we will add 4 million people, or more than currently live in the city of Los Angeles.

California's population growth has been accompanied by an equally robust economic explosion. The State's economy is currently one of the most powerful in the world, producing nearly $500 billion of goods and services annually (Wells Fargo Bank 1986). This ranks California sixth among the world's economies. The State's economic growth is characterized by what economists term advanced industrial development. This means that the economy has become dominated by rapid advancements in communications and transportation technology, growth in service sector firms and jobs, and a relative decline in the importance of primary resource industries.

Two groups of basic industries, high technology and diversified manufacturing, are accounting for 90 percent of the industrial job growth in this decade. California will account for fully 30 percent of all high technology jobs created nationally during the 1980's (Center for the Continuing Study of the California Economy 1982). In sum, this state is among the leaders of an important industrial transformation that has global significance.

The implications of this transformation for resource management and forest planning are multifold. First, of course, there are tremendous new requirements for resource goods like timber, recreation, water, and open space. Ironically, however, while California represents one of the top three producers and the top consumer of wood products in the nation, the demand for timber is being outstripped by demands for other goods and services. In a very real sense, our economic strength frees us, at least to a degree, to depend on wood products imported from other areas. But relatively fixed goods like recreation opportunity, water, and wildlife habitat are becoming more scarce, and, therefore, more important to California consumers.

Such change in the relative value of forest-based goods must be better incorporated into our planning models. More significantly, planners need to promote institutions to capture the economic value of these so-called noncommodity goods to fund the management costs of producing them (Binkley 1987, O'Toole 1988).

Second, although the majority of California's growth is around cities, rural areas are also experiencing increases in population. In fact, 10 of the 15 fastest growing counties, in relative terms, are in rural forest and rangeland areas (California Department of Forestry and Fire Protection 1988). The implications of this rural migration are many, including higher land values, landownership fragmentation, checkerboard patterns of alternative uses, and increased political conflict over traditional management activity.

From the standpoint of forest planning, one of the most compelling aspects of exurbanization is the need to evaluate the cumulative effects of development and management under dynamic conditions. As more people move into the woods, we must find ways to anticipate the environmental and economic consequences. This involves the capacity to look beyond the boundaries of an individual planning unit such as a national forest, to review behavior in a mixed ownership context, and to design adequate systems of mitigation.

Third, California's social and economic transformation has a strongly urban flavor. Cities, indeed megacities, are the center of action for high technology growth. Thus, while patterns of exurbanization are developing, more than 90 percent of our citizens live in cities and this proportion is expected to hold over time. City populations dominate our political landscape and this generally translates into an environmentally-oriented focus. A 1984 California poll (Field Institute 1985) indicated the dominance of an environmentalist perspective among Californians. The poll found that 27 percent of the population considers themselves to be environmentalists. Sixth-two percent believe they are somewhat environmentally oriented. Only 10 percent hold no environmental leanings at all. In response to a question on the need to balance growth with development, 27 percent favored slowed growth, 65 percent want a balance, and only 5 percent would like to see environmental protection relaxed to promote growth. These percentages hold steady across political affiliation, age, and other characteristics. Only place of residence, urban versus rural, makes a difference. Rural residents, on average, would like to see more growth. Additionally, the California poll was replicated quite well by the vote in November 1986 on Proposition 65, a so-called clean water initiative.

Strong environmental sensitivities have several political and planning effects. First, there is general support for large-scale environmental projects. The 1984 California Wilderness Bill, which added more than 2 million acres of wilderness in the state, is one such example. Another is the establishment and expansion of Redwood National Park. Current proposals include several new national parks in the desert and along the Smith River in

Northern California. Such large-scale events cannot be ignored by planners. One of the primary reasons our national forest plans are behind schedule is the difficulty the Forest Service has had adjusting to the wilderness bill. The spotted owl issue can be viewed as a similar phenomenon.

The urban dynamic in environmental politics also means tremendous political competition over forest planning. Interest and environmental groups adopt various strategies to influence planning. Politicians make careers over support or opposition to resource decisions. Currently, although the Department of Forestry and Fire Protection has been designated a lead role in commenting on national forest plans, other departments in state government and the State Attorney General have made contrary and contradictory sets of comments.

This intense political competition over resource decision making has to be addressed by planners. And because of the competition, additional statutory help to ensure improved coordination or to further rationalize planning is not likely to be forthcoming. Planners must take the initiative on their own to coordinate diverse interests and energies towards a common purpose. Legislatures will not do this for them.

Planning as Negotiation

One approach to reaching a consensus on goals and means is a system of planning as negotiation. As mentioned, we are currently attempting to develop such a process in California. There are at least eight characteristics to this type of planning (table 1). These can be described briefly as follows:

1. Planning as negotiation deals with broad-scale social, economic, and political trends affecting forestland use and management. As I have tried to demonstrate, various social patterns beyond the land base are having a substantial effect on California forestry. Such patterns cannot be ignored by planners. We must develop more sophisticated approaches to modeling alternative scenarios that represent the resource-related implications of dynamic demographic, social, and political trends.

   Importantly, significant efficiencies can be gained through collaborative development of common data bases and analytical tools in this area. There is no reason for each national forest or for Forest Service Regional office and the state to develop separate sets of projections. We can all benefit from cooperation in trend assessment activities.
2. Following suggestions by Irland (1986), planning needs to recognize that goals are not fixed, but variable. In fact, one of the primary purposes of our project is to open up the debate about the goals of forestry and to recognize their dynamic nature. One of the primary purposes of planning, and one of the best tools planners have, is to force people to think strategically about the future.
3. A corollary proposition is that negotiation focuses on interests and not on issues. Issues can be sexy and draw public attention, but interests represent more fundamental, and perhaps more flexible, perspectives on the value of forests. Focusing on interests rather than positions can work for two reasons. First, for every interest there usually exist several possible positions that can satisfy it. When you look behind opposed positions for motivating interests, alternative positions that meet the interests of several groups can often be found. Second, reconciling interests rather than compromising on issues works because behind opposed positions lie many more interests than the conflicting ones (Fisher and Ury 1983).

Table 1.--Characteristics of planning as negotiation.

1. Deals with broad social, political, and economic trends.
2. Deals with situation in which goals are not fixed, but variable.
3. Focuses on interests, not positions.
4. Deals with multiple ownerships, agencies, and interests.
5. Invites all parties to the table.
6. Insists on using objective criteria.
7. Creates options for mutual gain.
8. Treats institutions as real, not assumed.

[1] *Adapted from Irland (1986) and Fisher and Ury (1983).*

5. Successful negotiation depends on the involvement of all parties with some stake in forestland and resource use. There are obviously multiple parties concerned with forestry's future in California and they need to be included at each phase of the planning process. A recent study of public involvement in commenting on the Tahoe National Forest draft plan demonstrates the alienating and polarizing effects of running public involvement as a beauty contest (Fortmann and Lewis 1987a).

   Essentially, three objectives should direct public involvement in planning:

   a. to elicit participation from a representative as a sample of the public and other agencies as possible;
   b. to elicit participation in a process that provides the participants with the same information as the agency and that adequately and accurately reflects their knowledge and concerns; and
   c. to generate commitment to a final decision perceived by all parties as legitimate (Fortmann and Lewis 1987b).
6. Negotiated planning insists on the use of objective criteria. One of the important tenets of professional forestry has been the utility of rational decision making. FORPLAN (Johnson 1986), CALPLAN (California Department of Forestry and Fire Protection 1988, Davis et al. 1985), and other models represent important systems for quantifying and objectifying resource decision making. Unfortunately, as discussed below, they have not been linked sufficiently well to the actual decision making process. Yet, the more we bring standards of fairness, efficiency, or scientific merit to bear

on a problem the more likely are we to produce a solution that is wise and broadly accepted.

7. Planning as negotiation focuses on the development of options for mutual gain. Planning too often is seen as an analytical rather than a creative process. But what is most needed in forestry is a wide-ranging exercise in invention. We must learn to try to invent the future, if we are to have an important role in it.

   Too often, forest planning assumes a goal of allocating fixed resources under conditions of scarcity. While there is truth to this analogy, it generally forces us into a debate over how to divide up a fixed pie. Instead, we need to be more creative at broadening the options on the table. While the notion of mutual gain has a decidedly Pollyannese ring to it, we have hardly uncovered all the ways forests can be used, managed, administered, and protected. A major goal of planning has to be the development of new options for land use and management, and most importantly, of new options for administration and planning.

8. This latter point raises the issue that the institutional environment cannot be assumed as given. Forest planning and allocation theory cannot continue to assume away the need for, or the opportunities of, institutional adjustment. In many cases, the surest way of exploding the limits of a fixed pie is to open up an analysis problem to include new institutional alternatives. Examples might include looking at several national forests in combination, at a mixed ownership situation, or at the opportunities to change the way resources such as wilderness or water are administered.

One positive contribution, the so-called new resource economists have made to forestry discourse, is to challenge several of our institutional assumptions (O'Toole 1988, Stroup and Baden 1983). While "market solutions" hardly hold all the answers, proposals for wilderness endowment boards, public cooperations to manage national forest timber, and new fee arrangements for recreation do open our eyes to new approaches. To date, the idea of altering the institutional structure of forestry has been largely the purview of those outside the forestry profession. But, such ideas are the essence of forest planning as negotiation.

Analysis Requirements for Planning as Negotiation

Even with this cursory view of planning as negotiation, some technical support requirements spring to mind. Davis (1988), in an accompanying paper, describes a decision support information system suitable for multiple-party negotiation on forest planning. I will simply develop several themes for consideration.

A first point is to recognize that the primary use of system analysis in planning as negotiation is to provide a quantitative representation of options for mutual gain. Consequently, models that allow simulation of alternative scenarios rather than an optimal solution of a fixed planning problem are most appropriate. In practice, optimization techniques may have considerable value as information generation tools. But a premium is placed on the development of an analytical capacity to simulate the effects of large-scale social trends--and of policy options--on land condition, management strategy, and economic, social, and political conditions.

Such analysis systems need to be large-scale, flexible, and relatively generic to be useful. As an example, FRRAP has been working towards the development of a simulation model and data base to represent all forest and rangeland ownerships in California. CALPLAN (California Department of Forestry and Fire Protection 1988, Davis et al. 1985) allows for the representation of the effects of changing demands and demographic patterns on the behavior of all public and private landowners, by region of the state and vegetation type. It is flexible in that any combination of ownership, vegetation type or condition, geographic location, or forest output can be addressed. Thus, we can look at several national forests in combination, at a mix of public and private owners in a given water basin, or at all forestlands in an economic region.

Such capacity is required to address many forest policy issues that arise in California and is a analytical prerequisite for generating options for mutual gain. It is not enough to model the tradeoffs among different combinations of forest uses (Connaughton and Fight 1984), one must also represent how various trends affect those levels of use and how a combination of policy options can result in different social and economic outcomes. In addition, plan alternatives must incorporate the political and institutional changes required to bring them about.

To such an end, planning as negotiation requires analytical procedures that are accessible and understandable to the participants and affected interests of forest planning. Binkley (1987) has noted the ways in which the use for FORPLAN has excluded important people from the national forest planning process. From a negotiation perspective, the process of analysis only makes sense if it allows interests to sit down and "make deals" to arrange contracts for transferring resources, to link plans, and to vary the institutional environment in order to achieve mutually beneficial goals (Davis 1988). In other words, planning as negotiation requires us to develop models that decision makers can understand and use as they engage in negotiation. Such models must allow planning participants an opportunity to incorporate their own knowledge and information into the process, to keep score as negotiations proceed, and to invent options for mutual benefit.

Benefits and Consequences

Various authors have noted that the legislative planning statutes of the 1970s have not resolved all conflict over forestry, nor made it possible to meet all demands on forestlands (Behan 1979, Dana and Fairfax 1980). Planners in California find these observations to be compelling. We exist in a dynamic social environment that provides much uncertainty and scant opportu-

nity for consensus on issues. Nevertheless, strategic planning procedures and options can be developed to gain greater influence over the future.

One such approach would be a collaborate approach to forest planning perhaps involving the Forest Service, University of California, Berkeley, and California Department of Forestry and Fire Protection. Based on a model of planning as negotiation, this project would attempt to chart a new course for planning in California. It would put planners in something of a new role. Rather than focusing on analytical systems that met the bottomline of statutory direction, an effort would be made to actually address the problems we face. This process does not place planners above democratic procedures, rather, it forces us to use them. The goal is to discover new ways to use, manage, administer, and protect the state's forests, so they can play a relevant role in California's future.

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Definition of the Integrated Federal-State Planning Problem

Lawrence S. Davis[1]

Abstract--Integrated Federal-State planning (IFSP) requires joint and simultaneous consideration of planning and policy options on all Federal, State, and private lands within the State. Virtually all analysis of related problems is limited to single decision maker, multiobjective programming (MOP) techniques, primarily goal programming. The IFSP problem differs in two important respects: it is a multi-decision maker, multiobjective problem, and it considers multiple landowners within a common problem formulation. Analysis of the IFSP problem is directed to providing information about feasible aggregate choices and educating and facilitating negotiation by the multiple decision makers involved in the problem. California is used as a case study to illustrate the definition of the problem. Initial results show the strong aggregate tradeoffs at the State level between retention area and/or budget vs. timber, forage, water, and developed recreation.

The Integrated Federal State Planning (IFSP) problem is defined in the context of a State's concern with independent planning by federal, state and private landowners within its political borders. States, particularly the Western states, want to evaluate and comment on the aggregate and cumulative effects of proposed changes in the management plans of one ownership sector, such as the Forest Service, in terms of outputs from all ownership sectors. Increasingly, the states are contemplating policy and programs that enhance beneficial and will prevent or mitigate adverse collective effects of wildland planning. Such actions will politically involve all landowners and affected interests in the IFSP problem.

Assembling comparable, comprehensive information about all wildlands and all owners is difficult. Typically each federal agency, state agency and private organization keeps its own data base, has a different analytical system, and sets a different timetable for collecting data and planning. As a result information is not easily arrayed to portray and evaluate combined effects. Moreover few States have invested in obtaining and organizing the needed information and most are just now struggling to define their role in Federal-State planning.

Forest Service planning under RPA/NFMA is a significant agenda item in many States and is challenging their ability to work with the IFSP problem. Exacerbating the problem is the Forest Service's treatment of each forest as an independent planning unit. Draft plans for the forests within a State are released at different times over 10 to 20 months and the only effective option given the State is commenting on a plan-by-plan basis in order to meet the 90-day NEPA comment period constraint. This particularly impacts the Western States that need to process and evaluate up to 20 individual plans. What the State wants is for all plans to come out at about the same time and/or to have a year or more for comment after the last plan is released.

Several States are now making a serious effort to assemble the needed information and interact with the Forest Service at the State level of aggregation. Idaho requested a statewide analysis of the aggregate and cumulative impact of Forest Service plans on the State's economy and employment. Oregon, where timber supports some 50 percent of the State's economy, is mounting a comprehensive review directed from the Governor Goldschmidt's office to assess the combined impacts of projected Federal and private timber supplies on the Oregon timber economy and to develop a substantive State response to Forest Service plans. California is just finishing a comprehensive assessment of all private industrial and non-industrial forest and rangelands within the State to project production of timber, forage, wildlife habitat, water, and recreation. This information, when coupled with Forest Service DEIS data on the planning choices for 17 National Forests, presents a comprehensive

[1] *The author is Professor of Forest Management, Department of Forestry and Resource Management, University of California, Berkeley.*

picture of what the future may hold for California if all plans are implemented.

If any institution is going to coordinate the current independent planning of resources, it would have to be State government. Only the States have a clear and vital interest in the collective effects of land use within their boundaries. Moreover they are the political unit with enough clout to force serious evaluation and coordination of land use planning activities over multiple public and private ownerships. Integrated Federal-State planning is actually something of a misnomer; we are really talking about integrated planning of public and private lands under the presumably benevolent and enlightened direction of Federal and State governments. Private landowners and private interest groups are understandably suspect of public motives and will insist on full participation in any such process. Four developments are needed to make IFSP function: (1) a clear formulation and articulation of the State's interest and role in Federal Planning, (2) the existence of incentives for private landowners and affected interests to consider integrated planning, (3) development of a suitable decision support information system to evaluate and display aggregate choices and their consequences from many points of view, and (4) the design of an appropriate forum, participant list and negotiation procedure for integrated Federal-State planning.

The primary objective of this paper is to give a more formal definition of the Integrated Federal-State planning problem as a decision problem and to outline one scenario as to how an interactive, multi-decision maker negotiation process might approach its solution. A secondary objective is to suggest how a modified goal programming formulation might be a suitable framework to organize information to support the negotiation process. A quantification of the model for DEIS plan choices currently defined for California National Forests is presented as a case study and some initial results discussed.

Formulation of the IFSPP as a Decision Problem

This paper assumes that the Federal and State land agencies have decided that significant net social gains can be realized through coordinated planning and they agree to jointly work at effecting an integrated planning process. Analysis and decision making for the IFSP problem is assumed to have limits on time, budgets, and other planning resources. Moreover, like all planning, the goals of the participants and the aggregate constraints on the problem change with time. Hence this planning problem is characterized as a continuous problem for which discrete periodic decisions are made to allocate resources and implement activities and policies. Planning tries to capture this constantly evolving problem through a quantitative "snapshot" that is analyzed to help guide decision making, fully aware that by the time the decision is made the snapshot is out of date and a new one needed. Periodic decisions are administratively made by individual landowners in an open, politicized negotiation process involving governments, other landowners, and affected interests. In this broad outline, the process is about the same as that prescribed by regulation for National Forest planning. The important differences are twofold: the existence and recognition of multiple decision makers--active participants with different goals and agendas--and the explicit inclusion of multiple land ownerships in the formulation of a common problem.

Participants in the IFSPP

People representing Federal, State, and private landowners, Federal, State, County, and City governments, and major affected interest groups such as water users, recreationists, commodity, and environmental interests will want seats at the negotiating table. Each interest is treated as an independent decision maker with a different set of goals and different weights on the importance of outputs from the forests. Procedurally, selecting a workable number of participants to actively represent this broad spectrum of interests will be a major issue.

Let d_j represent decision maker j, j = 1...j

q_i represent forest output of type i, i= 1...i

Outputs and Activities

If each of the representative decision makers were interviewed and asked to state the relative importance of the different forest outputs and activities to their goals on a scale of, say, 0-9, we would expect their initial statements to provide a result such as illustrated in table 1. The weighting of decision makers such as d_1 or d_4 suggest they might be hired staff representatives of organized interest groups with narrowly defined interests, explaining the zero weights assigned to many outputs. Others, such as d_3 or d_4, might represent public agencies or government units who tend to take a comprehensive view and consider nearly all outputs to be of some importance.

A first order need of analysis is to identify which forest outputs and activities to quantify and track. This requires formalized interview and relative assessment, particularly with the multiple decision maker problem where the list of outputs of import to at least one person will be long.

Table 1.--Relative value of forest outputs to different decision makers measured on a 0-9 scale.

Forest Output q_i	Decision maker d_j			
	d_1	d_2	d_3	d_4
Timber harvest	9	5	4	0
Water yield	3	7	2	0
Acres old growth	0	2	1	9
Developed recreation	0	1	7	4
Forest jobs	0	5	6	0
Biological diversity	0	2	0	4

Decision Variables for Integrated Planning

Within the geographic boundaries of the State, forests and other wildlands are distributed over thousands of different private and many different public owners. Most of these ownerships are a single planning unit but some, such as the Forest Service or large industrial companies, are broken down into several individual planning units. For each planning unit, at a given point in time none, one, or more than one mutually exclusive plan has been developed and written for the management of the unit. A unit without a plan is being managed in some way, its just that a plan is not written or otherwise known and thus not currently available to the aggregate planners.

Let x_{lm} = plan l for planning unit m, l = 1...l, m = 1...m

and $\Sigma_l x_{lm} = 1.0$, for m = 1...m (plans are mutually exclusive)

Assume a State has four planning units. The list of unit plans available for consideration and analysis by our integrated state-level planners to consider might be as follows:

Unit 1, $\{x_{11}, x_{12}\}$ (Bureau of Land Management)

Unit 2, $\{x_{21}\}$ (Industrial Forest Lands)

Unit 3, $\{x_{31}, x_{32}, x_{33}, x_{34}, x_{35}\}$ (U.S. Forest Service)

Unit 4, {no data available} (Non-industrial forest lands)

Because each plan is a mutually exclusive choice for each planning unit, the complete set of aggregate choices available for State level consideration is all permutations of known mutually exclusive choices for the individual planning units.

Let S_k = aggregate choice k, k = 1...k

In our example no information is currently available on unit 4. Because of this, the aggregate State choices are initially quantified by plan choices from units 1, 2, and 3 with a blank for unit 4 (x_{4m}). Presumably an early order of business will be to obtain some information on unit 4. There are ten permutations in this example (2 x 1 x 5 = 10).

$S_1 = \{x_{11}, x_{21}, x_{31}, x_{4m}\}$

$S_2 = \{x_{11}, x_{21}, x_{32}, x_{4m}\}$

. . . .

. . . .

$S_{10} = \{x_{12}, x_{21}, x_{35}, x_{4m}\}$

To illustrate, a hypothetical data set for the unit plan choices (table 2) is aggregated to form State aggregate choices S_1 to S_{10} (table 3). Cost information is also included to calculate the budgets required by the various aggregate choices.

Two forest outputs are assumed to be of collective importance: volume of annual timber harvest (q_1), and forest acres reserved from timber harvest (q_2). When the set of 10 aggregate choices are mapped into decision space for this problem, we obtain a feasible region in terms of total state outputs (fig. 1). The feasible region is partitioned into subsets of choices that are available at budget levels of $1000, $1500, $2000, $2500 and $3000. The discrete aggregate choices are enclosed by the dashed line to suggest a contiguous feasible space that contains additional but as yet undefined choices. We cannot, however use the convex combination of the existing solutions to form new choices. This is because many such combinations may not be feasible when traced back to the actual planning unit and the full range of spatial and other unique local constraints are imposed. Since the aggregate choice is made up of mutually exclusive

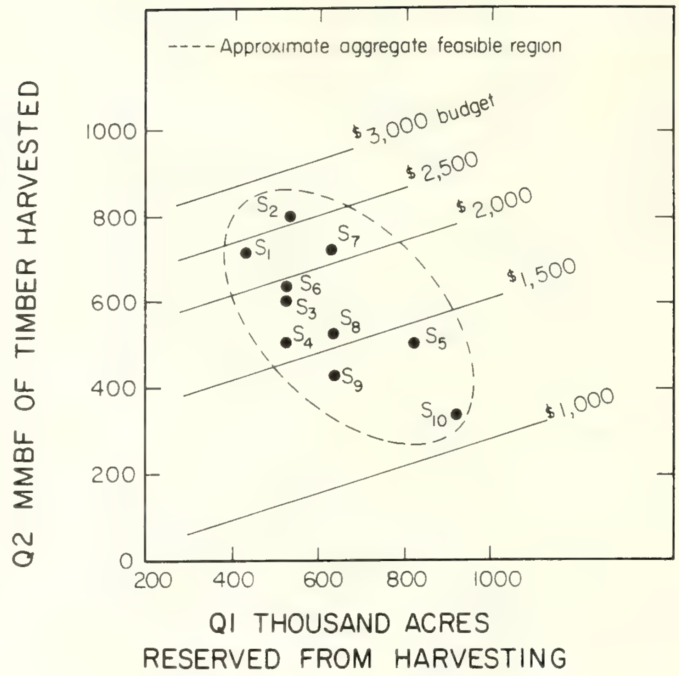

Figure 1.--Aggregate choice feasible region mapped in decision space.

Table 2.--Planning unit data for an integrated planning example.

Planning unit	Unit choice	Timber harvest *(MMBF)*	Area reserved *(M ACRES)*	Cost *(M$)*
BLM				
	X11	120	300	500
	X12	40	400	200
Forest industry				
	X21	200	10	600
Forest Service				
	X31	400	100	1000
	X32	500	200	1500
	X33	300	200	800
	X34	200	200	600
	X35	100	500	600
NIPF	X4M	--no data--		

Table 3.--Aggregate planning choices available to the state.

Aggregate choice	Planning unit elements	Timber harvest *(MMBF)*	Area reserved *(M acres)*	Aggregate cost *(M dollars)*
S1	X11 X21 X31	720	410	2100
S2	X11 X21 X32	820	510	2600
S3	X11 X21 X33	620	510	1900
S4	X11 X21 X34	520	510	1700
S5	X11 X21 X35	420	810	1500
S6	X12 X21 X31	640	510	1800
S7	X12 X21 X32	740	610	2300
S8	X12 X21 X33	540	610	1600
S9	X12 X21 X34	440	610	1400
S10	X12 X21 X35	340	910	1200

non-divisible unit plans, it follows that the aggregate choice itself is also mutually exclusive and non-divisible. At the very least, any new choice conceptualized as a linear combination of two or more existing aggregate choices needs to be disaggregated to the planning units and checked for feasibility prior to assuming the new aggregate is also feasible.

Evaluations of the Aggregate Feasible Set by Individual Decision Makers.

Two types of subjective approaches might be used by an individual decision maker to identify a preferred choice: (1) direct and (2) indirect. In the direct approach, the decision maker

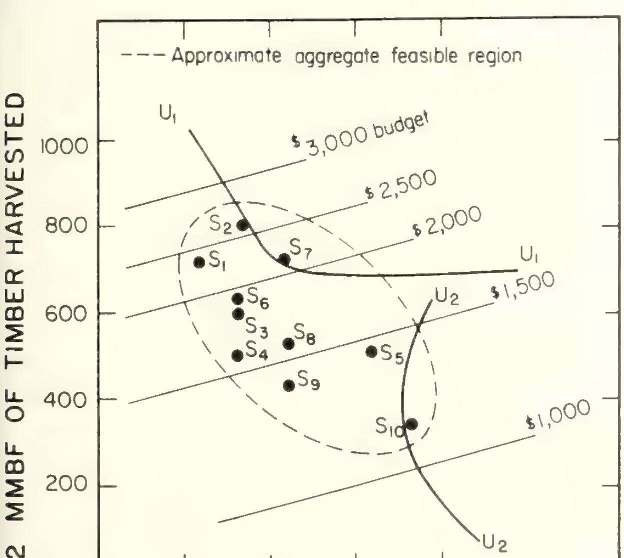

Figure 2.--Direct selection of aggregate choice from decision space.

accesses his or her utility function and directly select a preferred solution from decision space. Figure 2 illustrates this: the initial feasible region of figure 1 is examined by decision maker number 1 using her utility function U_1 to choose point S_7. The second decision maker, with a different utility function U_2, selects point S_{10} from the same feasible region.

In the indirect approach, the decision maker first attempts to articulate specific goals and then formulate an explicit objective function to calculate the goal value of each aggregate choice variable (S_k). These results are then used to map the feasible region from decision space into a feasible region in objective space. With this additional and more organized information, the decision maker's utility function is again used to make a final choice. To illustrate the indirect approach, considers two decision makers who each have the same two goals: income (Z_1), and aesthetic quality (Z_2). Where they differ is in their evaluation of how different outputs contribute to these goals. Table 4 shows how the two might assign relative weights to the outputs to form linear objective functions for each goal. The first decision maker

Table 4.-- Objective criterion coefficients used by two decision makers for calculating achievement of their income and amenity goals.

	Decision maker #1		Decision maker #2	
Forest output	Income goal	Amenity goal	Income goal	Amenity goal
Q1 Timber harvest	8.0	3.0	4.0	1.0
Q2 Reserved area	0.0	4.0	2.0	10.0

obtains about as much aesthetic pleasure from viewing the managed forest as she does from viewing uncut areas. She would calculate the amenity value of a given choice S_k as $Z_1 = 3q_1 + 4q_2$. The second decision maker is depicted as having a more narrowly defined sense of aesthetics: high values are placed on uncut natural forest and low values on managed areas and areas heavily utilized by people, resulting in his calculation of the aesthetic goal as $Z_1 = 1.0q_1 + 10q_2$. The differences in goal calculations only repeat the old saying "beauty is in the eye of the beholder;" they also are the reason why the multiple decision maker problem, once it is granted that all viewpoints are legitimate, will be difficult to resolve.

The outputs are weighted by the relative value weights for each goal of each decision maker (table 5). When the feasible region in objective space is mapped into decision space, a different map is created for each decision maker such as shown in figure 3. The decision makers again examine the feasible region with their utility functions and make a choice. In this example decision maker 1 switched from S_7 to S_2 after the more detailed evaluation while decision maker 2 maintained his

Table 5.--Value of outputs in objective space for two decision makers.

Aggregate choice	Decision maker #1		Decision maker #2	
	Income goal	Amenity goal	Income goal	Amenity goal
S1	5760	3800	3700	4820
S2	6560	4500	4300	5920
S3	4960	3900	3500	5720
S4	4160	3600	3100	5620
S5	3360	4110	3300	8520
S6	5120	4090	3580	5740
S7	5970	4590	3980	6790
S8	4330	3990	3380	6640
S9	3420	3590	2980	6540
S10	2720	4090	3180	9440

The objective values are calculated using the criterion coefficients from Table 4 and the outputs for the aggregate choices in table 3.

Decision maker #1

Income goal value = 8Q1 + 0Q2
Amenity goal value = 3Q1 + 4Q2

Decision maker #2

Income goal value = 4Q1 + 2Q2
Amenity goal value = Q1 + 10Q2

choice of S_{10}. The indirect approach does not avoid the necessity for the decision makers to subjectively weight the different goals. It only provides the decision maker more information and experience before the weights are assigned.

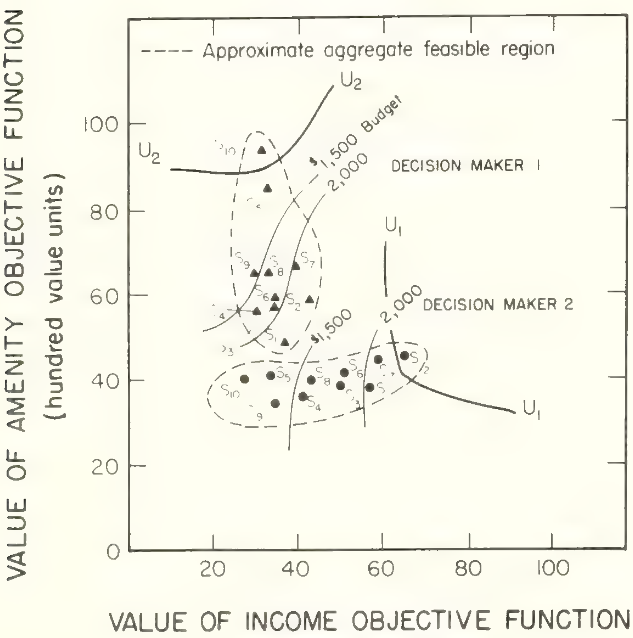

Figure 3.--Aggregate choice feasible regions mapped into objective space for two decision makers.

It's not clear to me whether participants in IFSP negotiations will want to use direct or indirect approaches. Probably some of both. The answer to this will not be known until the people involved are actually assembled and we learn their analytical comfort levels and they decide how they want to deal with the problem. Each group of participants will surly approach the problem in a unique way.

The process of identification of participant goals to select the most important outputs for quantification, and assembling unit plan options into aggregate choices to create a feasible region in decision space are common needs. These will constitute the principal analytical demand on an information system to support integrated Federal State planning. If, in addition, participants wish to use more formalized evaluations and tradeoff analysis to support their negotiations, then the information system can be usefully augmented by selected search, generation, filtering, optimization techniques of multiobjective programming (MOP).

Outline of a Likely Interactive Analysis and Negotiation Process for Integrated Federal-State Planning

Although the primary focus of this paper is designing an information and analysis system to support IFSP, design needs to anticipate the most likely ways in which the system will be used. The first and most basic assumptions are that laws, statutory authority, and political reality will allow a meaningful negotiating process to exist, and that important participants will have reason to come to the negotiation table. To be meaningful I mean that *participants must feel that within the negotiation process they have significant power to affect the outcomes.* Practically, this requires that representatives of different agencies, owners, institutions, and affected interests, both public and private, have the incentive and authority to sit down and "make deals" to transfer resources, increase budgets, change regulations and laws, and link plans in order to achieve common agreed upon goals. Meaningful negotiation is very different than the current "comment" approach where affected interests and decision makers comment on proposed plans of others but each planning unit manager makes almost fully independent decisions. The real power of the commentator is the implied threat of bad publicity, political pressure, or legal challenge.

Given that meaningful IFSP can exist, one scenario is outlined to suggest how negotiations might progress and interact with an information and analysis system. It assumes that the full scope of interested and affected interests are identified, classified, and a representational scheme agreed upon and that a manageable hierarchy of committees and negotiators is established. The process itself is conceptualized as a continuous series of short term planning cycles. During each 5- to 10-year planning cycle the participating negotiators strive to reach rough agreement on a long term collective land use strategy and more specific agreements on the activities, resource transfers, policies and programs to be implemented in the next 5- to 10-year period.

At the beginning of a planning cycle, analysts are assumed to have assembled available data and constructed an information base that describes the finite set of existing individual and aggregate planning unit choices, outputs and consequences. At this point the idealized 10-step procedure outlined below starts. Each step of this procedure is described and then illustrated with further development of the example started in tables 1-4 and figures 1-3.

Step 1. The negotiators invest in training to understand the character of the IFSP problem, some analysis basics, an how negotiation can work and benefit the participants. Training games using hypothetical or remote data sets could play a big part in this training, orientation step.

Step 2. The negotiators invest in learning the quantitative dimensions and important tradeoffs found in the existing feasible region for the IFSP problem of their State (fig. 2).

Step 3. The difficulty of evaluating Statewide aggregate choices without information for some planning units becomes intolerable to the participants. Estimates, however rough, are made of the most important outputs under existing management from the missing management units. For the example, this means Unit 4, the nonindustrial lands unit, is briefly studied and is estimated to provide 200MMBF of timber and effectively set aside 100M acres of unharvested large timberland. This new information results in an augmented and revised feasible region (fig. 4).

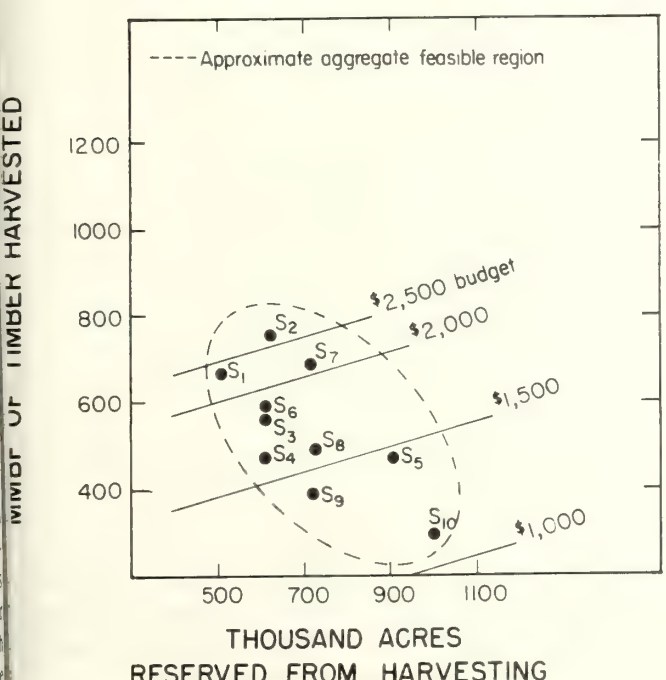

Figure 4.--Aggregate choices augmented by an alternative for the non-industrial planning unit.

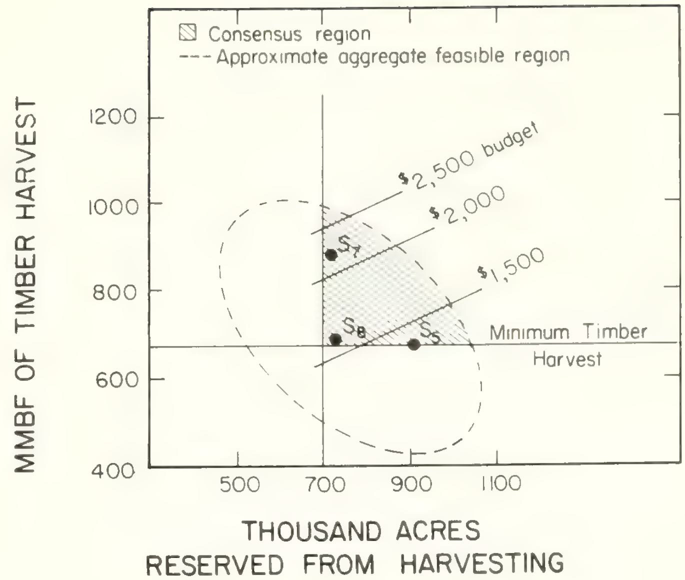

Figure 5.--First round consensus region negotiated in decision space.

Step 4. The negotiators attempt to delineate a subset of the augmented feasible region in decision space that is minimally acceptable to all interests represented. This highlights communication and procedural problems, identifies additional information needs, and help focus the more detailed examination and evaluation at subsequent steps. For the example, suppose a series of negotiations reveals that the minimum acceptable timber supply to the most demanding timber negotiator is 680MMBF and the minimum acceptable area to the most demanding amenity interest is 700M acres reserved from final harvest, creating the reduced feasible region in figure 5.

Step 5. To ensure that all important aggregate choices are politically and technically realistic, negotiators critically review the existing feasible region for accuracy and adequacy. Is it reasonable to assume that all existing planning unit choices are feasible? Which are suspect and which need more study? Are some aggregate plan options infeasible for political or legal reasons, or in terms of their assumed resources? If so, some planning unit choices may be deleted, aggregate constraints changed or added and the aggregate feasible region appropriately reduced. In the example, aggregate budgets of greater than $2000 are judged pragmatically unrealistic. Additionally a more careful analysis of available large timber acreage suitable for non timber harvesting reserves to be somewhat less than first estimated. A new maximum estimate of 900M acres is accepted by the negotiators (fig. 6).

Step 6. Existing unit plan options are examined to determine if they represent a full range of all possible feasible choices. Moreover, if additional aggregate resources and new multi-institutional arrangements are made available, what new choices are possible? This step results in direction to the analysts for generating new management unit choices to aggregate and augment the initial consensus feasible region. In the example, higher state budgets and a coordinated political effort is estimated to raise the aggregate budget constraint from $2000 to $2500. Innovative new alternatives for individual planning units are identified based on tradeoffs and linkages between planning units which provides the new aggregate choices S_{11} - S_{15} (fig. 7).

Step 7. In a series of negotiating rounds the augmented feasible region of step 6 is again reduced to a subregion that meets the realistic minimum or maximum bounds of all negotiators. A variety of generation, filtering and multiobjective programming techniques may prove useful to the negotiators in facilitating this process. The desired result is a consensus region containing a subset of aggregate choices from which a final choice will likely be made.

Step 8. Develop the "deals" between participants that provide the needed incentives and compensations to permit a specific choice to be selected and implemented. Additional MOP can be used here.

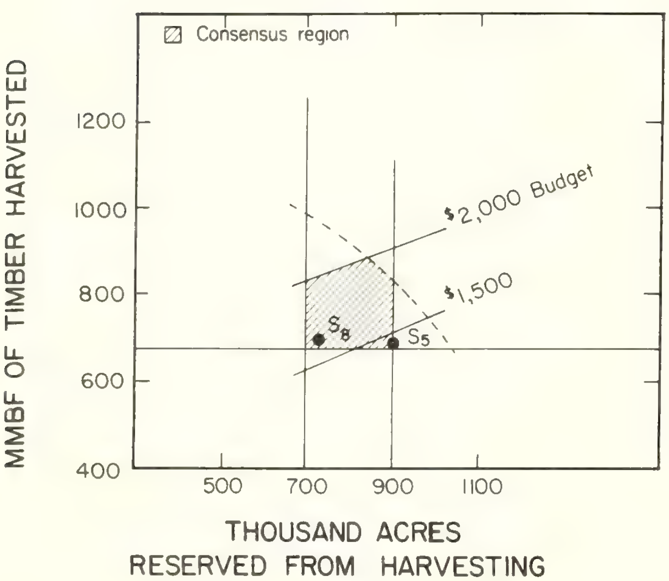

Figure 6.--Reviewed and revised consensus region in decision space.

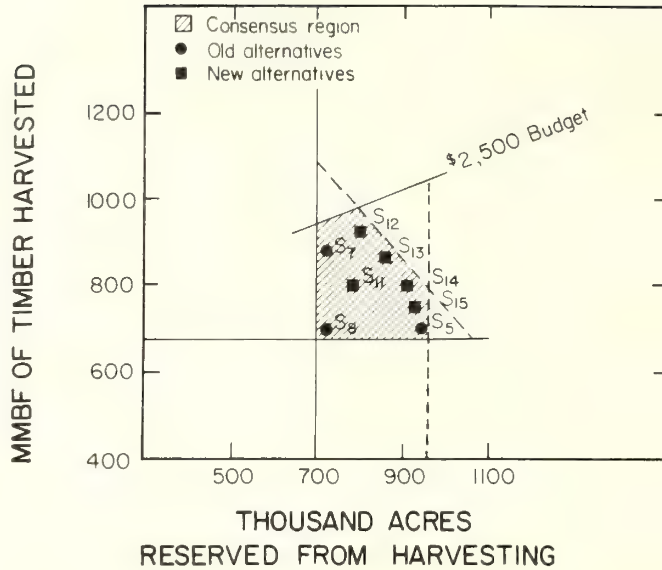

Figure 7.--Augmentation of revised first round consensus region t initiate second round negotiation.

Step 9. Final decision. Initiate the aggregate level resource and institutional arrangements needed to implement the selected choice for each planning unit. The decision itself will more than likely consist of partial coordination of some ownerships and the implementation of some new governmental policies and programs. Many ownerships will retain and implement their original preferred alternatives.

Step 10. Monitor and Continue, starting the next 5-10 cycle.

Available Analytical Methods

A substantial literature has emerged since the early 1970 showing many problem formulation strategies and optimizatic algorithms to deal with multiple objective problems. Virtual all of this material addresses public and private land manag ment problems as single decision maker problems with and tw or more goals. Goal Programming is the multi-objective pr gramming (MOP) technique receiving the most application Forestry (Arp and Lavigne 1982, Bell 1976, Dyer et al. 197 Field et al. 1980, Walker 1984). Steuer and Schuler (1978) use an interactive interval criterion weights/vector maximum a proach for public land planning problem but considered tl forest planning team to be "the decision maker." Hotvedt et a (1982) used a heuristic interactive procedure to develop go weights from the preferences of several different persons wor ing for the same private timber corporation.

The IFSP problem, as defined earlier in this paper, implicit or explicitly has *multiple decision makers*. It will be "solved,"

it can be solved, only through political negotiation. Cohon and Marks (1975) in their early multiobjective programming review paper recognize this important distinction and comment that when political feasibility is a primary consideration, it requires "definition of the next problem in public planning: the multiobjective multiple-decision maker problem."

Steuer (1986) has organized the fast developing field of multiple criteria optimization and provides an accessible body of principles in an effective textbook. Indirectly, however, he offers little hope for direct application of multi-criteria optimization techniques to the IFSP problem. In the introduction to his book he suggests that "whereas multiattribute decision analysis (which addresses problems with a small number of alternatives in an environment of uncertainty) has been most applicable in resolving difficult public policy problems...multiple criteria optimization is more useful with less controversial problems in business and government."

The IFSP would surely have to be classed as a highly politicized, "difficult and controversial public policy problem." In addition to multiple decision makers it has the full compliment of fuzzy (Bellman and Zadeh 1970) and wicked (Allen and Gould 1986, Liebman 1976) problem properties.

I have found few definitive suggestion in the operations research literature for dealing with the multiple decision-maker, multiple criterion problem, nor would I expect to. Using single decision maker optimization techniques for a multiple decision maker problem implies either *unanimity* or a negotiated *consensus* of all participants on goal levels, weights, and priorities. If such consensus is not forthcoming, the optimization techniques are strictly limited to an information generation role. By solving over a series of alternate goal and value structures, participants can be made much better informed of the shape of the feasible region in decision and objective space for themselves, and for each of the other participating interests. This may facilitate the negotiation and search process to find a consensus position.

To work with the IFSP problem, we may have to abandon insistence on considering only efficient solutions, because a given aggregate choice that is dominated in decision space may be non-dominated in objective space by decision makers that assign negative utility to some outputs and activities such as clearcutting. Similarly, the notion of optimality, if pushed too hard, may only serve to muddy communication between participants.

Setting aside the analytically powerful concepts of efficiency and optimality leaves little theoretical purity and analytical elegance, but systems analysis and operations research has this important job of helping society deal with very important multiple decision maker land management problems. The role of analysis will become more to define problems, to educate political participants, and to provide support information to facilitate interactive negotiations among people, some of whom are guided as much by emotion as the intellect in developing their positions.

A Modified Goal Programming Model for Integrated Federal-State planning

Bearing in mind the preceding definition of the Integrated Federal State Planning problem, the negotiation procedure scenario, and the inherent limitations of single decision maker optimality analysis when dealing with multi decision maker problems, a traditional goal programming formulation was modified to serve as an information system for the problem and negotiation procedure defined above.

Since each planning unit works up one or more discrete plan choices, these are viewed as package deals where any one alternative must be implemented completely or not at all. Hence this problem formulation treats each public planning unit alternative as a 0,1 integer variable. All alternatives for a given planning unit are mutually exclusive and only one plan can be chosen for implementation. All private land ownerships within a defined geographic area are classed as industrial or non-industrial, and each class is treated as a planning unit. Alternatives for the private planning units are different scenarios for how these lands will be owned and used in the future under existing and new policy packages. Accounting variables are defined to accumulate, for reporting and constraining purposes, the production of outputs, activities and consequences of interest from regional and statewide aggregations of the public and private forest planning units.

Goals are entered in combinations of four ways: (1) in the objective function as a weighted function of selected activities or outputs, (2) in the objective function as weighted deviations from desired levels of selected forest outputs, (3) as mandatory constraints on output or activities such as a minimum timber harvest or maximum acres clearcut in a region, or (4) as constraints that force pre-selected unit plan alternatives into solution.

Such a flexible goal structure can swing from single goal maximization, to a traditional goal program, to a pure simulation that calculates consequences of exogenously selected and hard-wired alternatives. The method of formulating goals and objectives will depend on how the people representing affected interests feel about articulating and negotiating their goals. Perhaps more importantly it will depend on their individual perceptions of the relative power they can achieve within negotiation vs. the power they can achieve through legal action, political influence and other means of achieving desired goals.

Aggregate Choices from California's National Forests: Some Initial Results of a Case Study

All planning choices in published DEIS for the 17 California National Forests were extracted and assembled in the goal programming framework outlined above. Each plan for each forest was treated as a mutually exclusive integer choice and the program was required to select one plan from each forest. Data on 6 priced and about 30 non-priced National Forest outputs was

included and tracked by four sub-regional groupings and totaled for the state in each of the first 5 decades covered by the plans. The "most likely" California FRRAP Assessment estimates for timber and forage outputs for these regions and time periods were also included in the model. Since at the moment we only have one private sector scenario, it is effectively a constant and therefore these initial results only look at tradeoffs within National Forest lands.

Exploring the Feasible Region

To initiate analysis, the feasible region of all possible aggregate choices from the National Forests was examined. To do this, the objective function was first set to individually maximize and then to minimize each of the six priced outputs plus retention acres and budget. The results of these independent maximizations and minimizations are shown in table 6. As we had suspected, the dispersed recreation showed little variation across all plans and developed recreation and anadromous fish but little more. Grazing and timber showed about a 50 percent increase from the minimum to the maximum. The timber range was calculated after the approximately 2000 MMBF cut of the private lands are subtracted from the total. Water outputs were measured as increments over the historic 70 million acre feet baseline level. As a percent of the base level, the most water productive set of National Forest plans only increase water by an estimated 525 thousand acre feet or a 0.6 percent increase over historic levels. Retention acres, those acres allocated for visual management purposes under sharply restrictive timber harvesting prescriptions, varied almost fourfold over the aggregate choice set and appear to be one of the most important tradeoffs with the commodity outputs. Appropriated budget costs of the alternatives also ranged substantially, nearly doubling in real dollar costs in each decade from the least to the most costly set of alternatives.

Table 6.-- First decade maximum and minimum output levels possible in Region 5 From current DEIS forest plan alternatives.

Output	Units	Decade	Min.	Max.	Max/Min
Anadromous fish	M lb.	1st	2796	3238	1.15
Dev. rec.	M RVD	1st	11164	14324	1.28
Dispersed & wild rec.	M RVD	1st	30035	32056	1.067
Grazing	M AUM	1st	520	739	1.42
Fed timber	MMBF	1st	1617	2523	1.56
Oth. timber	MMBF	1st	2000	2000	1.00
Total water	M ACFT	1st	70077	70525	1.006
Water incr	M ACFT	1st	77	525	6.82
Retention area	M Acres	5th.	1347	5116	3.80
Operating	MM	1st	248	401	1.62
Cost	1982$	2nd	273	422	1.54
		3rd	299	488	1.63
		4th	314	536	1.71
		5th	341	633	1.86
		current	300		

The tradeoffs between retention acres and budget costs and all other outputs and activities were evaluated. Using the data of table 6, five levels of budget were scaled at even 25 percent intervals between the maximum and minimum cost. Similarly five levels of retention acres were scaled between maximum and minimum levels. The objective was set up as a normalized goal program that minimized the unweighted sum of the percent underachievement of the maximum possible physical output levels for fish, timber, grazing, water, developed recreation, and undeveloped recreation. This objective treats all goals as equally important and is indifferent to goal overachievement. In this case, the aggregate goal of achieving all maximum outputs defines a solution outside the feasible region.

Five problems were solve using only the retention constraints. A second set of five problems were solved using only the budget constraints. Finally the retention constraint was set at each level and solved for each budget constraint level in a set of 25 runs to determine the joint impacts of the two constraints. In terms of the 10 step analysis and negotiation procedure previously outlined, this analysis only carries through step 2, the familiarization with the feasible region.

Retention Analysis

The five runs sequentially set a minimum required constraint on aggregate retention acres. The pattern of individual National Forest plans selected in the optimal solution is shown in table 7. Reading a row or column moving from left to right we see what happens as the retention constraint is relaxed from its maximum level of 5.1 million acres to the minimum level of 1.37 million acres. Predictably we start out with amenity and low budget alternatives for nearly all forests and then move to the higher timber output market, RPA and maximum cash receipt alternatives as the constraint is relaxed. Note that some forest such as the El Dorado and Lassen the high timber output alternative enters solution as soon as the constraint is relaxed one step. This likely means these forests have the highest direct rates of tradeoff between timber and retention acres.

In figure 8, the tradeoffs of primary outputs are shown measured in terms of percent achievement of maximum possible output levels. The tradeoff with timber is nearly linear over the region and range of retention acres. Since retention acres are presumably intended to be a proxy for visual management decisions and visual values, then visual vs. commodity poses a clear tradeoff. Yet this tradeoff is not clearly or forcefully articulated in many DEIS. The retention area tradeoff with a timber linked secondary output, county % tax receipts, is shown in figure 9. The partitioning of receipts by sub state region shows the timber rich Northern California to receive most of the county tax receipts.

Table 7.--Forest plan alternative selected at different levels of aggregate retention area constraints.

Planning unit	RET1	RET2	RET3	RET4	RET5
Retention acres	5116	4174	3232	2289	1347
National Forest	------Alternative Selected----------				
Angles	PRO	MKT	MKT	MKT	MKT
Cleveland	PRF	PRF	MKT	MKT	MKT
El Dorado	PRF	MKT	MKT	MKT	MKT
Inyo	AMB	PRF	PRF	RPA	RPA
Klamath	CEE	CEE	CEE	CEE	CEE
Lassen	AMN	RPA	RVW	RPA	COM
Los Padres	NOW	NOW	NOW	WLD	MKT
Mendocino	AMN	AMN	AMN	AMN	MKT
Modoc	AMN	AMN	AMN	RPD	IND
Plumas	AMY	AMY	CEE	CEE	CEE
San Bernardino	CUR	CUR	CUR	CUR	RPA
Sequoia	AMN	PRO	PRO	PRO	PRO
Shasta Trinity	MIX	MIX	CUR	CUR	CUR
Six Rivers	LOW	PFO	PFO	RPA	RPA
Sierra	LBU	PRO	PRO	PRO	PRO
StanislauS	ALT#A	ALT#A	ALT#G	ALT#G	ALT#G
Tahoe	AMN	AMN	RPA	TMB	TMB

Budget Analysis

It is recognized that most of the National Forest alternatives were developed without using budget constraints and that this has some merit as a budget planning device. However the State and the affected private interests also need to plan and respond

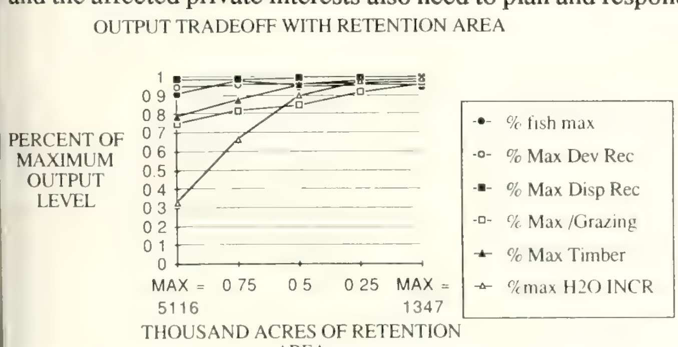

Figure 8.--Tradeoffs of primary outputsin terms of percent achievement of maximum ouput levels.

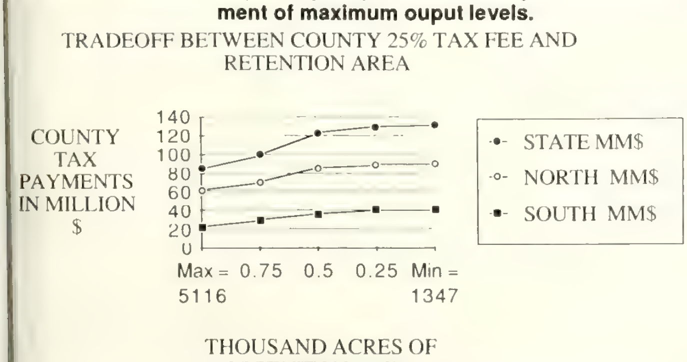

Figure 9.--Retention area tradeoff with a timber linked secondary output (county tax receipts).

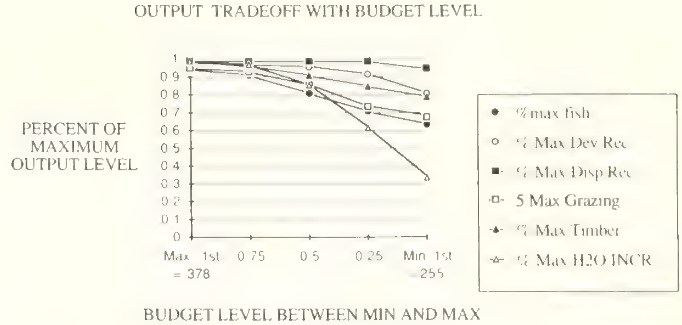

Figure 10.--Primary outputs at different regional budget levels.

pragmatically in terms of what they think the *actual* output levels from the National Forests will be. We have moved through nearly a decade of budget and personnel reductions and the Federal debit and financing picture is not one to encourage even committed optimists. It therefore seems prudent for the State and others to evaluate the current program plans of the Forest in terms of their costs and against what pragmatic estimates of future appropriated budgets will be. The primary outputs provided by the R-5 at different levels of budget are graphed in figure 10. The current budget of R-5 in 1982 dollars is approximately $300 million. This is shown on figure 10 as the vertical line BB. Water, grazing and timber again show significant responsiveness to budget. (Remember there is no retention constraint in any of these runs.)

The overall responsiveness to budget is substantially reduced for all outputs by the time 80 percent of the maximum cost budget is available. With this set of alternatives, additional increments of budget do not stimulate large changes in the outputs. It might be hard to justify the last increment after 90 percent of the high cost budget is reached.

At current 1982 budget levels the Region cannot finance the Preferred alternative for each Forest. Hence the State and others want to know what set of plans will be implemented if funding at around the current level is continued. To make the best use of limited funds, a different set of alternatives for each Forest needs to be generated. For a start, all the current alternatives could be reevaluated in FORPLAN using the current, slightly higher, and slightly lower budget levels constraints.

Joint Retention-Budget Analysis

For the joint analysis, the budget constraint was varied over all its levels for each level of retention area constraint. The level of timber harvest associated with these joint constraints is shown in figure 11. At retention levels of 5.16 and 4.17 million acres, timber is generally unresponsive to budget after the first budget increment. At retention levels of 3.2 million acres or less, there is a significant constant retention effect but timber shows an almost linear response to budget and, presumably, investment in timber production.

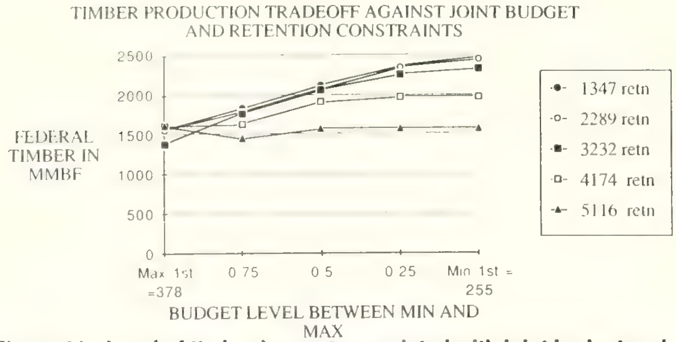

Figure 11.--Level of timber harvest associated with joint budget and retention constraints.

Water increments show about the same pattern as timber: little responsiveness to budget at the two highest retention levels and reasonably strong responsiveness at lower retention levels.

These joint results suggest that, given available forest plan options, increases in retention acres above about 3 million acres may have high marginal opportunity costs in terms of primary output production and general efficiency of budget use. Analysis to find out the causes+for these tradeoffs and interactions would be interesting. I cannot explain these timber and water results further without a thorough spatial study and evaluation of how each individual forest handled their visual management planning and how the retention and partial retention areas interfaced with timberlands and productive snowmelt areas. The DEIS numbers we see were, of course, filtered through the FORPLAN representation of the spatial problem and perhaps something was lost in the translation.

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Modeling Local Timber Economies for Land Management Planning, Policy Studies, and Timber Supply Analysis

Kent P. Connaughton, Neil McKay, Steve Haas, Duncan Campbell[1]

Abstract.--The Oregon State Forestry Department, the Pacific Northwest Region and the Pacific Northwest Research Station of the USDA Forest Service, and the Bureau of Land Management, are collaborating on a project to prepare a computer model of Oregon's timber economy. The model will facilitate land›management planning, policy analysis, and timber›supply studies. The model portrays the interactions between timber owners, wood›products manufacturing mills, and the domestic and international demand for products produced in Oregon. A test of a prototype model, along with suggestions for further research, including a probabilistic portrayal of harvesting and management on private forestland, are given in this paper.

What assumptions should planners and analysts make about the future demand for timber on the National Forests? What do the different land and resource management alternatives for the National Forests mean for timber harvest, stumpage prices, employment, and wood products manufacturing in the resource›dependent communities of the Pacific Northwest? Local›market modeling research at the Pacific Northwest Research Station should help the public land›management agencies and others answer these questions.

We are collaborating with the Oregon State Forestry Department, Bureau of Land Management, and the Pacific Northwest Region of the USDA Forest Service, to develop an operational model of the local timber economies in Oregon. The model will approximate the way actual markets work by portraying the physical production opportunities confronting timberland owners and wood products mills, and the economic and social forces affecting stand›management, harvesting, manufacturing, and plant-investment decisions.

Three broad purposes influence the design of the model: land›management planning in the public sector, analysis of policies affecting the timber resource, and analysis of future timber supply. Historically, analysts at the land›management agencies and the Pacific Northwest Research Station have used different techniques to prepare projections of timber supply and to analyze the consequences of land management and policy choices.

The local›market model project is an outgrowth of the agencies' desires to prepare mutually understood analyses of where Oregon's timber economy might go in the future. The specific purpose of the project is to prepare a computer model that can be used to prepare a broad range of technically defensible evaluations of public and private forestry alternatives.

As a first step in the project, we developed a prototype model of the local timber economies of southwestern Oregon. The model was implemented with the Generalized Equilibrium Modeling System (GEMS), a flexible system for modeling the interactions between timber suppliers, mills, and the final demand for wood products (Boyd et al. 1983). Projections of prices and quantities prepared with GEMS are conceptually appealing because they represent intra- and intertemporal equilibria between supply and demand across product and factor markets. Much of the remainder of the paper discusses the design and implementation of the prototype. The prototype is one of two major influences on our research.

The second major influence, also discussed, is the experience gained from implementing a simulation model of local supply and demand of timber in Oregon and Washington. We implemented the simulation model with DYNAMO, a software

[1]*Connaughton, McKay, and Campbell are research foresters, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208. Hass is a principal, Decision Focus Inc., 4984 El Camino Real, Los Altos, California 94022.*

system for modeling systems dynamics problems (Richardson and Pugh 1986). At first glance, the simulation model appears to be a crude local-market model because it portrays only timber supply and demand, lacks a manufacturing sector, and only approximates the intra- and intertemporal equilibrium between supply and demand that is called for by natural resource theory. The simulation model is important, however, because it includes two features that were not part of the prototype local-market model's representation of timber supply: (1) the model incorporated our full knowledge of the variation in the physical condition of the industrially owned resource, and (2) the model's structure opened up interesting possibilities for using statistically estimated probabilities to model harvesting and stand-management behavior.

Work is progressing to exploit the lessons learned in designing and implementing the prototype and simulation models. We conclude our paper with a view of where local-market modeling work is headed in the future, both as a researchable problem and as a tool for State and Federal planning, policy analysis, and timber-supply studies.

What Purposes and Issues Motivate Local-Market Modeling?

The need for better land-management planning, policy analysis, and timber-supply projections motivates local-market modeling research. Some specific issues the local-market model is designed to address are worth considering; the list of issues suggests the capabilities and technical requirements of the model.

Land-Management Planning

If you were on the planning staff of the Umpqua National Forest, headquartered in Roseburg, Oregon, you would be interested in the effect that each of the alternatives in the Forest Plan might have on the local wood-products industry and its associated employment and income. The results of such an assessment may not be obvious because the industry is confronting complex changes in raw material availability and quality, manufacturing productivity, and demand for its products. A knowledge of the management choices for the Umpqua, the role of the Umpqua and other forested land in supplying timber to meet the demands of the local wood-products industry, the characteristics of the industry, and the external forces affecting the industry are necessary to address this issue.

Policy Analysis

Policy analysis may require a knowledge of the timber economy that is comparable to the understanding implied by land-management planning. Policy issues commonly apply across ownerships and across management-unit boundaries. For example, management of the northern spotted owl and the transition from an old-growth to a second-growth economy are related policy issues that transcend unit boundaries and the different forest ownerships. Much of the owl's habitat is in old-growth stands located on Federal lands in western Oregon. Because old-growth is unevenly distributed, some communities can expect to feel more heavily than others the effects of management measures that restrict old-growth harvest to protect owl habitat. To address these effects, one needs to understand the probable management strategies that the public agencies might adopt, and where and when these strategies might be implemented.

Timber-Supply Analysis

Timber-supply analysis requires an understanding of the variation in the timber resource and the differences in opportunities, policies, and objectives that affect the behavior of public and private forestland owners. All agencies collaborating on the project have an interest in the timber-supply situation in Oregon. The Forest Service and BLM are committed to consider supply-related issues in their plans. As a complement to the plans for the individual National Forests in Oregon and Washington, the Forest Service has prepared an assessment of how the plans can be expected to affect local, State, and regional harvest on all ownerships during the period covered by the plan, and how the plans can be expected to influence the supply possibilities for the ensuing decade. The Oregon State Forestry Department must comment on the Federal plans and prepare an independent assessment of the future of Oregon's forest resources (the Forestry Program for Oregon). Finally, analysts at the Pacific Northwest Research Station must assess the implications for future timber supply in Oregon of data collected on non-Federal ownerships.

Conclusion: The Market Model as a Common Means to Address Timber-Related Issues

The market model will be a tool that each agency can use to prepare analyses that can be understood by the other agencies. Results will be technically consistent with the opportunities and behavior of timber suppliers, mills, and wood products markets. Users will be able to display simultaneously the local, State, and regional consequences of public and private forestry alternatives.

Each public agency can bring its perspective to planning, policy, and supply-related issues. The perspective of the Federal land-management agencies is to know where the Federal lands and resources fit in an economy that has extensive, privately owned timber lands and resources. The analysts at the Pacific Northwest Research Station and colleagues in the private sector want to know where non-Federal forests fit in an economy

/hose future depends importantly on Federal forestry. The)regon State Forestry Department wants to constructively valuate Federal planning alternatives, and provide a credible, omprehensive view of the entire Oregon timber situation. 'ommon to each perspective is a set of factors--notably the roductivity and technology of the processing industry and the emand for manufactured wood products--that influence forstry and the forest industry but that are not subject to control by ınd managers.

Design of the Prototype

We identified six design criteria before work began on the rototype. The design criteria were the link between the model's urpose and its technical implementation. The design criteria lso served as evaluation criteria; if we had been unable to nplement any one of the six, we would have (in the best case) eturned to the drawing board, or (in the worst case) aborted the roject.

'ortraying Supply and Harvest on Public Lands

We wanted analyses done with the local›market model to omplement analyses of land-allocation and resource-scheduling choices. Therefore, we decided that the timber programs on he public land management units (National Forests, BLM Aaster Units, State Forests) had to be included in sufficient letail to capture the factors that influence the harvest of public imber. Examples of such factors are location, quality, and pecies characteristics.

To model public›sector behavior, we separated the public gencies' decisions to offer timber for sale from purchasers' lecisions to harvest timber. This allowed us to treat the harvest chedule associated with a land›management alternative on a iven National Forest as an intertemporally related family of upply curves. Demand, purchaser's willingness›to›pay for imber offered for sale, was modeled separately. No requirement vas imposed on the market model that public timber offered for ale be harvested if no economic rationale existed for doing so.

'ortraying Harvesting and Management on Private Land

We wanted the harvesting and management decisions of the ıdustrial and farmer ownerships to be analyzed within the ıarket model and consistent with economic opportunities to ·ofit from growing and harvesting timber. This allowed us to present behavior as a problem of optimally choosing among ultiple harvest timing and management intensification op›ons. We also decided, as an approximation to reality, that pply from the other›private ownership should be a insensitive prices or other economic factors.

Portraying Manufacturing and Investment

We wanted both the decision to produce different manufactured products and the decision to expand or contract plant capacity to be analyzed within the model and consistent with economic opportunities to profit from manufacturing. This allowed us to project production and changes in capacity as a function of existing mill technologies, and changes in timber availability, conversion costs, product demand, and conversion efficiency.

Portraying Transportation Flows

We wanted to represent the flow of logs from the woods to major processing centers. This allowed us to explicitly represent transportation costs as a variable affecting harvesting, stand-management, product manufacturing, and capacity›investment decisions.

Portraying Market Equilibria

To achieve our goals of realistically portraying forest management and milling decisions, we wanted price and quantity results to be consistent with the intra› and intertemporal equilibria of supply and demand. This criterion required that supply and demand be in equilibrium across product and factor markets in any period, and that future prices and costs be considered in making harvesting, private stand›management, processing, and plant›investment decisions.

Sensitivity Analysis

The timber economy is a complex, dynamic system. The principal value of the local›market model is to learn how the timber economy will evolve as a function of different land›management options, different assumptions as to the behavior of landowners and millowners, changes in technology and utilization, and changes in wood›products demand. Therefore, the ability to evaluate efficiently a wide range of scenarios in an understandable, credible manner was a prime objective in designing the prototype.

Structure of the Prototype

The structure of the prototype model mirrored the structure of the actual timber economy (fig. 1). Demand for manufactured products, the processing industry, and timber supply were all explicitly represented; prices were the signals that affected management, harvesting, and investment behavior.

To implement the design criteria, we disaggregated this general structure to reflect differences in location, production

possibilities, and behavior of timber suppliers and the wood-products manufacturing industry. The disaggregation reflected the design criteria, the availability of data, and the structure of GEMS.

Timber Supply

We modeled separately the timber supply for industrial, farmer, other-private, and public owners.

The production possibilities for the industrial and farmer ownerships were represented using a stratum-based portrayal of the resource. Forest Inventory and Analysis (FIA) inventory data for these owners were delineated into strata defined by timbershed, productivity class, stand condition, and stand-age attributes. A yield schedule was prepared using DFSIM (Curtis et al. 1982) for each stratum comprised of precommercial stands. Strata characterized by more mature (natural) stands were projected using normal yield functions based on Bulletin 201 (McArdle 1927). DFSIM was used to generate a portfolio of managed yield alternatives, representing a range of management intensities, for acres regenerated after final harvest. For all strata, the yields were expressed not only as total volume by decade but as volume within three log-diameter classes.

Industrial and farmer owners within each timbershed were assumed to maximize present net worth by selecting an optimal sequence of harvest and stand-management activities. The optimization decision was based on maximizing current and future returns from harvesting and managing timber, and reflected the differential pricing of logs in each of the three diameter classes. Farmers were assumed to face a higher alternate rate of return than industrial owners. Harvest from other-private owners was projected as a constant volume equal to its trend over the period 1975 to 1984.

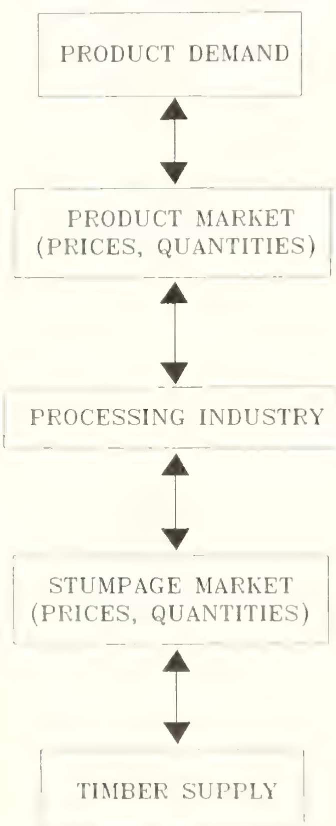

Figure 1.--The structure of the local-market model.

Supply curves, describing the relation between extraction costs and volume of timber offered for sale, by decade, were developed for three National Forests, five Bureau of Land Management Sustained Yield Units, and the Elliot State Forest. Extraction costs were defined as the costs, exclusive of stumpage, that timber purchasers would experience if they harvested public timber. The supply curves for the three National Forests were developed from preliminary harvest schedules and extraction costs prepared early in the current round of National Forest planning; supply curves for the BLM and State were developed from harvest projections reported in published plans.

Whenever the information was available, we prepared separate supply curves for existing stands, commercial thinnings, and the stands to be regenerated in the future. We also subdivided the Siskiyou National Forest into parts east and west of the Oregon Coast Range, and prepared separate sets of supply curves for each part. Volumes on each step of the supply curves were proportioned by the three log-diameter classes used to describe the private resource.

Public timber was assumed to be harvested from the quantities offered for sale, according to whether extraction costs were less than or equal to the value of the harvested timber. Therefore, though no assumption was made that all public timber offered for sale would be harvested, the supply schedule represented an upper bound on what the harvest volume could be during any decade.

The Processing Industry

We recognized two outputs (lumber and plywood) and three mill technologies (dimension mills, cutting mills, and plywood mills) for each of three processing areas in southwestern Oregon. The processing areas included all milltowns within a geographically defined area; the boundaries of the processing areas were drawn so that the mills in the included communities would have similar transportation costs from the many timber suppliers represented in the model.

Three manufacturing technologies were represented not only because each optimally produces a different mix of products, but because each optimally uses a different mix of log sizes. We modeled millowner decisions for each technology by assuming that they maximized profits based on the physical input-output efficiency of converting logs of different diameters, the costs of manufacturing (including the cost of expanding plant capacity), and the prices of manufactured products.

Implementing the Model with the Generalized Equilibrium Modeling System (GEMS)

We chose to implement the prototype model of the southwestern Oregon timber economy with the Generalized Equilibrium Modeling System (GEMS); GEMS is proprietary to Decision Focus Inc. of Los Altos, California (Boyd et al. 1983). The reasons for choosing GEMS were threefold: (1) the theory underlying GEMS--that markets tie together the separate optimizing behavior of many different parties--is intuitively and conceptually consistent with the way Oregon's timber economy works; (2) GEMS is a tested, flexible software system for analyzing the types of market-related problems confronting us; and (3) the solutions calculated with GEMS implement the theory of renewable natural resources in such a way that intra- and intertemporal equilibria across markets can be calculated.

GEMS is composed of three basic elements:

1. A library of generic subroutines or process models describing the behavior of different agents (timber owners, mills, and the demand for manufactured products) in an economy.

2. A network, specific to the model being implemented, describing the interactions among the processes. The GEMS network describes the timber economy as an economic system, and includes transportation links, conversion processes, and the feedback of price signals to influence what occurs in each process model.

3. An algorithm for determining the numerical values of all the variables in the model. Because forest-management and industrial-investment decisions are inherently forward-looking, we were seeking the GEMS capability for calculating intertemporally optimal solutions for particular process models.

A GEMS model is ideal for representing markets because it s not solved for the optimal behavior of an entire economic sector as a whole. Each process model represents instead ndividual optimizing behavior, and the model is solved for the lynamic market interactions of the collection of individually optimizing agents. The algorithm used to solve the model finds he set of variables (prices, quantities, management activities, and capacity additions) that satisfies the physical and behavioral elations embodied in the process models and the linkages among the processes.

The distinctive process model in the prototype model of the outhwestern Oregon timber economy was private timber supply. It represented the variety of physical conditions and choices escribing the industrial and farmer ownerships, by location, nd, using optimal control techniques, modeled their harvesting nd management behavior as a dynamic, profit-maximization roblem.

Sample Results

Sample results from the prototype illustrate the capabilities we seek in an operation model of Oregon's timber economy.

Figure 2 displays harvest, by owner, for southwestern Oregon. The projections cover the next 50 years. The projections are the summation of public and private harvests, by local area. A parallel set of equilibrium stumpage prices was projected for each owner.

Figure 3 shows some of the detail that would be useful for land-management planning. The figure shows a comparison between the quantity of timber offered for sale on two of the three southwestern Oregon National Forests, and the quantity that is projected to be harvested from these Forests. The difference between scheduled and harvested is the result of the economically undesirable characteristics of the unharvested timber. This comparison highlights what is probably already known on those two Forests: that certain stands scheduled for harvest under current plans are economically marginal.

Figure 4 shows a comparison of the output of dimension and cutting mills over the next 50 years. Though total timber harvest will undergo a downward adjustment because of the falldown in

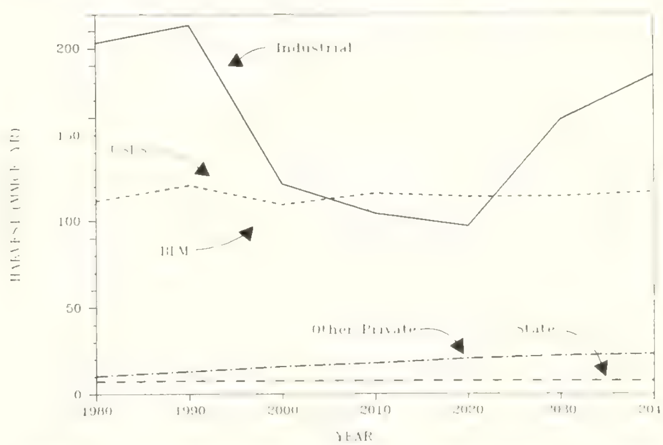

Figure 2.--Projected harvest, by owner, for southwestern Oregon.

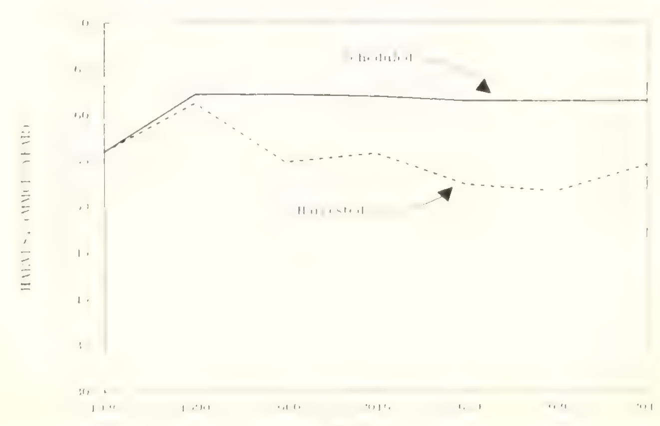

Figure 3.-- A comparison between volume scheduled for harvest and volume projected to be harvested on two National Forests in southwestern Oregon.

industrial harvest, the output of the different types of lumber mills will change dramatically as the quality and characteristics of harvested timber changes.

Cutting mills face an immediate falloff in production and employment. Cutting mills depend on the large diameter logs typically associated with old-growth. These mills produce a larger range of products, many having higher value, than do dimension mills. Employment per unit of output is also higher in cutting mills than dimension mills. The significance of figure 4 is that it demonstrates one possible future in the transition from an old-growth to a second-growth economy. The corollary to this drop in output is that cutting mills will depend primarily on Federal timber because the remaining old-growth stands are on Federal land.

These results were not intended as operational analyses of the southwestern Oregon economy because of the simplifying assumptions made for the prototype. These assumptions would necessarily be refined or discarded in an operational model, and data would be updated to reflect our latest knowledge of the resource, the processing industry, and the demand for products.

What Did we Learn from the Simulator?

The prototype model of the southwestern Oregon timber economy was well received by the collaborating agencies and other reviewers. But we learned some valuable lessons in 1987 from designing and implementing a simulation model of the demand and supply for timber in Oregon and Washington. Those lessons will affect future market-modeling work.

The simulator lacked many features of the prototype market model, and the use of DYNAMO imposed many more restrictions on modeling supply and demand interactions than was true with GEMS. But the simulator also incorporated an important enhancement: acreage represented by each industrial timberland plot (from the FIA database) retained its identity in the calculations of harvest and management. That is, for each plot on industrially owned timberland, we specified a yield (production) function consistent with the initial stand conditions of that

Figure 4.--Projection of production by cutting mills and dimension mills in southwestern Oregon.

plot. We used the Stand Projection System yield simulator (Arney 1986) to derive these functions by projecting the sample of trees measured on each plot.

The team found this plot-based approach technically feasible, computationally straightforward, and free of concerns on how to define strata that would adequately describe the variation in the privately owned resource. The method was realistic, exploiting to the fullest our knowledge of the variation within the industrial resource.

Harvest was simulated to occur in stands (plots) for which the returns from harvesting exceeded the costs of harvest plus the maximum profit foregone by not delaying harvest to a future time. The ability to portray industrial harvest within each timbershed was not impaired by using such a highly disaggregated representation of the resource. Industrial harvest was simply the sum of the volume harvested for each plot expanded by its appropriate acreage expansion factor.

Where are we Headed?

As we develop an operational model of the Oregon timber economy and move toward a similar model for Washington, further research will be required. We discuss six enhancements underway or contemplated.

Representing the Private Resource With FIA Plots

We believe that the plots-based approach to modeling the private resource is better than the stratum-based approach used in the prototype. The stratum-based approach required that we aggregate plots with similar characteristics and, therefore, represent all acres within the stratum with the same average set of yield attributes. The plots-based approach allowed us to retain our full knowledge of the variation and characteristics of the private resource and to tailor yield schedules specific to the initial stand conditions on the plot.

Probabilistic Representation of Behavior

Our portrayal of harvest and management behavior of private owners was broad, deterministic, and focused on long-run projections. The individual-plots approach presents innovative opportunities to achieve greater realism in portraying behavior and land-base shifts, and to calibrate projections during the first decade more closely to historical trends. Specifically, using probit and logit analysis and Markovian techniques, we will estimate the probabilities that a particular plot will be harvested or subjected to specific silvicultural treatments or shifted to a different owner class or land use. No comparable link between probabilistic behavior and a stratum-based approach is as easy to implement, because strata, unlike individual plots, are not sample observations for which probability functions can be readily estimated.

More Efficient Data Handling and Yield Projections

We are considering the construction of a preprocessor program that will efficiently specify alternative yield schedules for individual plots or strata. Currently, the local›market model requires a vast amount of yield›simulation work, all of which is done for a set of intensification scenarios by manually running an appropriate stand simulator.

Improved Representation of Diameter Distributions

Currently, the diameter distributions associated with any particular stand are crude. This information can be refined by exploiting available information measured for each plot about individual tree diameters and heights.

Expanded Representation of Manufacturing Options

We propose to model at least four different lumber products and two plywood products. The lumber/plywood dichotomy obscures some product niches for which Oregon's forests have a comparative advantage in providing raw material. We also intend to prepare scenarios that would recognize the introduction of new manufacturing technologies or product lines into the Oregon timber economy.

Improved Representation of Final Demand

We have underway a Delphi study of the future of the demand for several lines of wood products manufactured in the Northwest. The objective is to systematically sample recognized experts to understand their individual and collective opinions of the future of the demand for the Northwest's wood products. The study is being conducted by Jay O'Laughlin of Texas A&M University. We hope to make his results available to all users of the local›market model.

Conclusion

Experience with both the prototype and simulator have been encouraging to ourselves and others. Local›market modeling is technically feasible: the theory, techniques, and data are available to develop such models. More important, perhaps, the overlapping perspectives of the public land›management agencies on the resource management choices facing them can be technically accommodated within the framework of the model; the model, therefore, provides a mutually understood way to analyze a common set of problems.

An important question remains: "Are we simply replowing old ground with a new machine that will give us the same old answers?" Although many of the timber›supply issues addressed by our predecessors can be addressed with the local›market model, important gains are promised. The model captures the entire timber economy within Oregon's borders and links Oregon to the outside world's demand for products and logs; the focus, therefore, is not just timber supply. As a corollary, the complementarity between public land›management plans and the market model allows users to comprehensively understand and display considerably more than the timber›supply consequences of resource-management choices. The promised gains require further work before we can declare them fulfilled; experience thus far, however, suggests that we are on the right track.

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Multi-Purpose Management of Forest Resources

Martin Fogel, Peter Ffolliott, and Aregai Tecle[1]

Abstract.--A framework for applying multicriterion decision-making techniques to the management of southwestern United States ponderosa pine forests is presented. The procedure consists of stochastic precipitation and temperature models as inputs into simulation models of forest products and decision-making routines that evaluate alternatives considering environmental consequences and recommensurate values.

It is well recognized that the United States Forest Service and, in some instance, other land management agencies are required by law to produce alternative forest management plans that provide for the multiple use and sustainability of goods and services that maximize long-term net public benefits in an environmentally sound manner.

The purpose of this paper, therefore, is to outline a methodology for evaluating and selecting a particular forest management plan that will best meet the desired objectives without undue stress on the environment. In formulating the problem in the proposed framework, consideration is given to a variety of silvicultural practices and/or cultural treatments that may be selected for a specific area. At the same time, it is recognized that most forest lands are not homogeneous in soils, topography, geology, vegetation, etc., such that a forest must be treated by a number of practices. Then, as the hydrologic regime transcends the entire watershed, a logical basis is provided for ascertaining the environmental implications of a management practice or treatment by analyzing the hydrologic outputs from a watershed.

FRAMEWORK

The proposed decision-making process for selecting the "best" management plan consists of (l) a time series of meteorologic inputs (primarily precipitation and temperature), (2) a set of models that simulate the outputs from a forest (e.g., water, timber, and forage), which includes the environmental consequences of management decisions, (3) the development of alternative plans, and (4) decision-making techniques for selecting the best alternative for meeting agreed-upon objectives.

[1]*Professor, Watershed Management and Research Scientist, School of Renewable Natural Resources, University of Arizona, Tucson, AZ 85721.*

Simulation

Simulation has been used to represent the dynamic process for a wide variety of situations in forest management. In simulating large-scale forestry systems, key parameters and variables can be systematically varied to allow monitoring system performance under a range of conditions. A dynamic simulation model is a representation of such a system as it evolves in time. Thus, a stochastic approach, the result of simulation of both inputs to and outputs from the system, allows for consideration of a variable hydrologic regime, vegetative growth to take place and its hydrologic implications and for the implementation of management plans over time.

In this approach, a time series of daily precipitation amounts and temperatures are developed and used as inputs into deterministic forest, range, and watershed models to produce a synthetic record of hydrologic and environmental outputs. The use of synthetic records are suggested inasmuch as the historical record may not be long enough to include records of extreme events.

Multicriterion Decision Making

The management of forest resources is a complex process that may often involve attempting to meet competing or conflicting objectives. Furthermore, the assessment of certain values, such as aesthetic factors, either enhanced or diminished by a management decision, is often controversial as these values can not be readily quantified in economic terms.

The stimulus for using multicriterion decision-making techniques is essentially based on the position taken by the Forest Service in their scheme of management that requires alternative plans to be produced that provide for the multiple use and

sustained yield of goods and services from the National Forest system in a way that maximizes long-term net public benefits in an environmentally sound manner (U.S. Forest Service 1982). Thus, management appears to recognize that the ecological setting of natural resources in a forest ecosystem requires careful consideration of the physical, chemical, biological, and other relationships such as socio-economic and institutional, that may arise when one or more of these resources are artificially affected.

The use of multicriterion decision-making techniques for a forest system will be discussed later in this paper.

HYDROLOGIC SIMULATION

As with any system, inputs are transformed into outputs via some mechanism. In this case, hydrologic variables/primarily precipitation and temperature) are inputted into a watershed model to produce such outputs as water yield, sediment yield and water quality indices.

Meteorologic Inputs

To properly evaluate the impacts resulting from altering the hydrologic regime of a forest, a time series of meteorologic inputs are required of sufficient duration that extreme events or combination of events are considered. For example, problems of erosion are usually not caused by moderate storms, but from these that have a probability of occurring at least once every 50 or more years. It can make considerable difference in an economic evaluation if a storm has an exceedance probability of 0.02 or 0.002. Also, drought implications can be more severe from two consecutive moderately dry seasons than from one real dry season. Existing precipitation records may not always contain such a situation. A brief discussion follows on precipitation and temperature models.

Precipitation

Event-based precipitation models developed over the past 20 years at the University of Arizona, are the basis for developing a synthetic record of precipitation inputs into watershed, range, and other models (Duckstein et al. 1972, Duckstein et al. 1979, Fogel et al. 1974, Fogel and Duckstein 1982). First, the seasons (generally two, summer and winter) are separated based on meteorologic conditions as the short-duration, high-intensity, localized summer-type convective storms are markedly different from the winter frontal storms. These events are defined, and then Monte Carlo simulation is used to produce one likely time series or a number of equally-likely series of individual events. Using a synthetic time series based on the statistics of an existing record, tends to assure that extreme events are considered in the evaluation process.

Temperature

Daily temperature is modeled as a stochastic process using two elements, one deterministic and the other probabilistic. The first element is a simple harmonic function which describes the long-term daily means of maximum daily temperatures; this can be either a basic sine or cosine function. To account for the daily means and the many short-term cyclical patterns observed within any one year, a probabilistic component is incorporated. Since the current day's temperature is somewhat dependent on the prior day's temperature, some form of auto-correlation is required.

Daily temperatures are introduced into the snow accumulation and melt routines of watershed modeling and into the crop and range production models.

Hydrologic Outputs

A deterministic watershed model transforms a series of daily meteorologic inputs into a time series of outputs that include water yield and such environmental indicators as sediment yield and other water quality indices.

Water Yield

While no existing hydrologic model has universal appeal, some do exist that if properly calibrated and tested can give reasonable results. That is, they are sufficiently sensitive to determine consequences of land use changes and, most importantly, to silvicultural practices. Examples of general continuous watershed models are the Stanford Watershed Model (Crawford and Linsley 1966), the "Sacramento" or the National Weather Service-California Department of Water Resources Model (Burnash et al. 1973) and the USDA Hydrograph Laboratory Model (Holtan et al. 1975). These models require both precipitation and streamflow data for calibration in estimating a number of parameters.

In the case of ungaged watersheds, where snow-melt runoff is not considered, the most probable model choice will be one based on an USDA Soil Conservation Service procedure which has a computerized formulation (U.S. Soil Conservation Service 1983).

Where only augmented streamflows resulting from vegetation modification are required, an approach suggest by Ffolliott and Fogel (1986) may be used. In contrast to the above models, which uses daily precipitation to produce water yield on a daily basis, this approach uses seasonal or annual precipitation.

Environmental Indicators

Another class of hydrologic outputs include sediment yield, chemical loadings, and other water quality indices. These outputs are usually sub-routines to hydrologic models and as

such, they require additional parameter estimates and their outputs are often subject to question.

Forest Product Simulation

For this study, the forest resources that are simulated are water, herbage, and timber. The hydrologic simulation, presented in the previous section, becomes an essential factor in the simulation of herbage production. Timber growth and yield models, however, do not require daily inputs of precipitation and temperature.

Herbage Production

Prediction models of herbage production are available that use daily inputs of meteorologic variables and estimates of site parameters. Examples are the model developed at Colorado State University (Gilbert 1976) and the one developed by the Agricultural Research Service of the USDA (Wight and Skiles 1987). Both models include a forecasting procedure that utilizes either historic or synthetic data, principally precipitation and temperature.

Timber

Harvest flows represent the timber volumes removed over time from existing timber inventories or stock supplies of stumpage. Modeling of these flows consists of two components, land allocation and timber growth and yield, and involves the dynamic interrelationships between biological and economic forces.

One class of models often used are the variable density growth and yield models, which are constructed to provide both growth and yields corresponding to different stand densities. Such models are of great value in contributing to the ability to represent potential results of different silvicultural management alternatives (Alig et al. 1984). Such models have been constructed at the University of Arizona and elsewhere.

Multicriterion Decision Making Applied To Forest Management

The purpose of this section is to discuss the applicability of multicriterion decision-making (MCDM) techniques to a forest resources management situation in terms of problem formulation to include the development of a "typical" set of objectives, specifications, and criteria and some of techniques that may be used.

Problem Formulation

Forests possess numerous resources and other support elements which may or may not be readily quantified. A management scheme for such an area can be described using non-commensurate objective and data consisting of cardinal, interval, and ordinal information. Such problems need to be presented in a format suitable for MCDM analyses.

Objectives

According to the U.S. Forest Service Multipurpose Forest Management Guidelines (U.S. Forest Service 1982), there are eight goals and four support elements in a National Forest management plan.

The goals involve:

1. Water yield
2. Timber production
3. Recreation
4. Wilderness
5. Wildlife and fish
6. Range
7. Minerals
8. Human and community development

The following are considered as support elements because they are essential for the development and appropriate management of natural resources, so that the above goals can be realized in specified manner.

1. Land
2. Soil
3. Facilities
4. Protection

To evaluate the relative merits of a number of alternative plans using MCDM procedures initially, the problem should be specified in terms of objectives, specifications, criteria, and criterion scales. An example of this is shown in table 1.

Evaluation Matrix

The next step in the problem formulation is to develop an evaluation matrix, which is an array of outputs based on various criteria for a number of selected alternatives. Table 2 presents an example of this array. The criterion weights in this array are selected to reflect the decision-maker's preference among the given set of criteria. A range of scales may be used to measure the degree of discomfort the decision maker may experience in moving from the "best" to the worst scale point in one criterion compared with a similar operation on another.

DECISION-MAKING TECHNIQUES

The most well-known decision-making technique is without a doubt goal programming (Cohon 1978). Initially it was

Table 1.--Objectives, specifications, criteria, and criterion scales.

Objectives	Specifications	Criteria	Criterion scales
Increase water yield	Increased flow; Water quality	Increased water yield; Sediment yield	Volume (AF/Ac); Volume (tons/ac)
Improve range condition	Livestock and wildlife forage; Habitat range	Forage; Production; Habitat status; Range condition	Lbs/Ac; Ordinal;* Ordinal; Ordinal
Develop recreation	Recreational (various kinds);	Aesthetics	Scenic value
	Preservation of existing facilities;	Level of preserving existing facilities	Ordinal
	Creation of new opportunities (hunting, roads, camping site, etc.)	Possibility of creating new facilities	Ordinal
Maximize commercial benefits	Timber; Livestock;	Timber sale; Livestock value;	&/Acre &/Acre
	Firewood, fence post and stumpage.	Firewood and fence post	Ordinal
	Streamflow;	Water yield	&/Acre
Optimize resources utilization	Operational cost; Maintenance cost; System operability	Total cost Ease of operation	&/Acre Ordinal

**Ordinal implies a 5-point qualitative scale ranging from a = best to e = worst.*

employed almost exclusively in the private sector, but of late, it has been used most extensively in natural resource management problems (Dykstra 1984). This section will present first description of three other types of techniques, two of which are the outranking type as exemplified by ELECTRE I and II (Duckstein and Gershon 1983) and the distance-based technique of compromise programming (Zeleny 1982). A more detailed description of these two methods as applied to forest management is found in Tecle et al. (1987). Another technique is one that is called the Evaluation and Sensitivity Analysis Program (ESAP), which is a general-purpose software aid to decision making that can be adapted for use in many disciplines (Mumpower and Bollacker 1981).

ELECTRE I and II

These outranking techniques have been developed to determine a preference ordering among a discrete set of alternatives with respect to a set of criteria by pairwise comparisons of the alternatives. Important elements in these two alternative actions m and n is a weighted measure of the number of criteria for which m and n is a preferred to n. The discordance index, on the other hand, represents the maximum discomfort one experiences when confronted with criteria for which m is not preferred to n.

In addition to the concordance and discordance equations, the ELECTRE II methodology uses a strong and weak ranking relationships among the alternatives in order to bring about a

Table 2.--Evaluation matrix (criteria versus alternatives).

Criteria	Wt.	Scale	Alternatives 1	2	3	4	5	6
1. Streamflow (AF/Acre)	9	200	0.509	0.673	0.650	0.480	0.710	0.780
2. Sediment yield (in tons/acre)	7	150	0.030	6.020	0.360	0.040	0.050	0.160
3. Forage prod. (lbs/acre)	8	180	329	833	126	325	460	490
4. Range condition	7	150	B	D	A	A	B	C
5. Habitat condition	8	100	C	E	B	A	B	D
6. Preservation of existing facilities	5	100	A	E	B	B	D	D
7. Creation of new facilities	6	75	E	B	C	C	B	B
8. Aesthetics (scenic value)	8	150	2.100	1.200	2.500	2.000	1.850	1.420
9. Timber prod. (current $/AC)	8	200	1644	16	1777	3147	3225	3273
10. Livestock prod. (current $/AC)	6	150	0.548	2.010	0.200	1.120	2.400	0.940
11. Firewood and fence post	4	80	C	E	B	B	B	D
12. Water yield (current $/AC)	8	150	10.17	13.45	13.00	9.530	14.20	15.52
13. Total cost ($/AC)	7	150	0.000	160.0	54.00	89.00	134.0	118.0
14. Ease of operation	4	120	A	B	C	D	D	C

Note: wt. = criterion weight.

complete preference ordering of the alternatives. The strong and weak outrankings are then defined by pairing individual levels from each index. One alternative strongly outranks another when a pair consists of high concordance and an average discordance threshold values, or have a pair with an average concordance and a low discordance values. On the other hand, an alternative weakly outranks another when either the concordance and discordance pair of threshold levels provided are both low, or both are average. Once the strong and weak outranking relationships are constructed, a complete ordering of the non-dominated set of alternatives may be obtained.

Compromise Programming

This technique is designed to identify solutions which are closest to an ideal point by some distance measure (Zeleny 1982). In a discrete setting, the ideal solution is defined as the vector of best values selected from a quantified evaluation matrix. The vector of worst values represents the minimum objective function values, these values are valuable in determining the degree of closeness of an alternative to the ideal solution.

EVALUATION AND SENSITIVITY ANALYSIS PROGRAM

ESAP can analyze a large number of variables (objectives) which are specified and organized by the user into a hierarchy or "tree." The user provides a goal for each variable and weight (importance) for each goal. The intellectual roots of ESAP lie in the field of decision analysis generally and in multiattribute utility theory in particular.

After each variable is assigned a weight, the user specifies values for each variable or factor, usually in terms of maximum and minimum levels. These levels indicate the range of available data or outputs from simulation models. Where no specific data are available, the values are based on an ordinal scale, and since they are subjective, the user can indicate an uncertainty in their value by specifying a range.

Then for each factor, a utility function translates these values into a common term, utility, which allows the user to assess the performance of each alternative course of action. This approach to selecting the "best" alternative for forest management has an appeal because it is straightforward in approach.

DISCUSSION AND CONCLUSIONS

Most if not all of the simulation models and decision-making techniques presented herein have been used in a variety of packages. In some instances, problems have developed such as in parameter estimation and in reliability, dependability, and reasonableness of results. Nevertheless, the approach is sound and with newer and better models and techniques and with more data, the objectives can be overcome. Thus, a general conclusion of this effort is that the use of simulation models as inputs into multicriterion decision-making techniques is a viable approach for managing forest resources.

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Multilevel Planning in a Spreadsheet Environment

Reuben Weisz[1]

Abstract.--This paper describes a multilevel approach to planning and budgeting within the spreadsheet environment of the Forest Service. Spreadsheets are arranged in a pyramidal and hierarchical fashion which defines the flows of information from one level of the organization to the next. Experience gained from applying this approach to the Southwestern Region is presented. The spreadsheet approach to multilevel planning is compared and contrasted with earlier approaches which advocated the use of mathematical programming to accomplish the same objective.

Introduction--Multilevel Planning in the Southwestern Region

When viewed from the perspectives of local, regional, and national planning, the Forest Service is a hierarchical organization. A typical depiction of the participants in the vertical hierarchy follows:

1. President, Congress, and the Judiciary System
2. Secretary of Agriculture
3. Chief of the Forest Service
4. Regional Forester
5. Forest Supervisors
6. District Rangers

The topic of the next paper in this session is hierarchical resource allocation mechanisms. My paper describes a spreadsheet mechanism for resource allocation in a hierarchical organization.

The preceding paper dealt with another aspect of managing the National Forests--the fact that we are involved in multiple use management. The participants in this vertical hierarchy are engaged in one or more aspects of managing timber, soil, water, air, range, wildlife, recreation, and cultural resources; protecting these resources from fires, insects, diseases, and pollution; and utilizing these resources with improved production, marketing, engineering, and citizen participation.

All National Forests in the Southwestern Region will have published final Forest Plans this year. The standards and guidelines in these Plans reflect decisions about how the Forests will be managed during the life of the Plan--a 10- to 15-year period. All actions taken within that period of time are directed at implementing the Plans. An evaluation or feedback process is included to indicate whether corrections and revisions of Plans and actions are needed. At the project level, an IRM (integrated resource management) approach has been adopted for implementing Forest Plans. This is a thirteen-step process which represents a horizontal hierarchy or multiple-step implementation process through time. The thirteen IRM steps are:

1. review the Forest Plan,
2. develop the project concept,
3. conduct extensive reconnaissance,
4. prepare a feasibility report,
5. update the Forest 10-year implementation schedule,
6. conduct intensive reconnaissance, survey, or design,
7. generate and compare alternatives,
8. alternative selection,
9. prepare NEPA documentation,
10. create a project record,
11. prepare a project action plan,
12. field implementation, and
13. monitoring and evaluation.

[1] *Operations Research Analyst, U.S. Department of Agriculture Forest Service, Albuquerque, N.M.*

In the above IRM process, the multilevel spreadsheet is ıtilized in steps 5 and 13. In the Southwestern Regional Office, he multilevel spreadsheet is used for the following activities:

1. preparing annual budget proposals,
2. issuing budget allocations,
3. evaluating partial level budgets,
4. tracking the results of monitoring,
5. conducting general management program, and activity reviews,
6. making the required 5-year Forest Plan implementation review,
7. evaluating the need to amend or revise Forest Plans,
8. communicating with the public,
9. consolidating data from other information systems,
10. establishing project priorities,
11. tracking accomplishments,
12. adjusting skills and organization,
13. defining information needs,
14. preparing the RPA Assessment and Program,
15. responding to Congressional requests for budget line item information by Forest and Region, and
16. conducting the performance appraisals of Forest Supervisors and Regional Staff Directors.

Why Use Spreadsheets Instead of Mathematical Programming?

Nationally, the Forest Service is a large organization with pproximately 800 offices and 35,000 employees. As the preeding discussion indicates, our Region is operating in a multiple level, multiple purpose, multiresource, multiple use, ıultiyear environment that has both vertical and horizontal ierarchies and processes. We need a fast, cheap, simple, fficient, and effective means of acquiring, analyzing, interpretıg, displaying, and transmitting information to planners and ecisionmakers at each level of the organization. We need ıiform and consistent information which can be used in all lated processes--data which is credible and comprehensible to ɔth ourselves and to our interested publics. The software ilized for processing this information should be compatible ith existing office automation software utilized throughout the ational Forest System. The hardware requirements for procsing this information should be the existing network of stributed processing facilities available throughout the ornization. A comparison of the pros and cons of a spreadsheet proach with a mathematical modeling approach using any and all of the above criteria indicated that the spreadsheet concept was the most appropriate technology.

Of supreme importance in implementing multilevel modeling is the human relations aspect of the analytical process. Too often, analysts are overly concerned with the mechanics and theoretical niceties of our analytical systems; see Hof and Pickens (1986) for example. However, the effectiveness of a system depends on whether the managers it affects understand it, accept it, and use it. Rightly or wrongly, the time-consuming, costly, "black box" experience associated with our large-scale mathematical programming endeavors in the past has engendered a fear of paralysis from analysis which is associated with sophisticated models. In contrast, a spreadsheet procedure using hardware which is within an arm's reach of each Forest Service employee using familiar software becomes fast, cheap, and accessible.

Meetings, such as the one that we are attending today, often are devoted to techniques which can only be utilized by the top percentile of analysts and computer acrobats in the organization. However, to be effective in a large complex organization, a technique may need to be geared to the lowest common denominator of computer literacy, hardware and software in that organization; a spreadsheet approach comes very close to hitting this target.

One of the major arguments against a spreadsheet approach is that it is too simple. (Note: this is one of the main arguments for a spreadsheet approach, as well.) Simply aggregating Forest Plans to a Regional level, or proportionately spreading Regional targets and budgets to a Forest level will not result in the most efficient output mix to be produced or the most efficient means of producing it. While this is true, efficiency analyses have already played an important role in the development of Forest Plans. Spreadsheets don't have to solve all of our analytical needs. Other analytical systems which focus on efficiency analysis, such as network analysis models, can be used in conjunction with spreadsheets in the Plan implementation process.

Criteria other than efficiency (for example, equity and effectiveness) play a major role in Plan implementation (Weisz and Stewart 1987). Spreadsheets are a good enough technology for handling these other criteria.

The mathematical programming approach in a multilevel organizational environment is most consistent with a centralized approach to planning and decision-making which places maximum constraints and the minimum amount of freedom on lower levels of the organization. In contrast, the spreadsheet approach in a multilevel organization is more congruent with a decentralized approach to management which provides minimum constraints and maximum freedom to the lower levels of the organization. A major benefit of the decentralized approach is that Forest Supervisors and District Rangers have the best information concerning local conditions and therefore are better able to make site specific resource decisions than those who are employed in the Regional Office. Lower level line officers gain valuable management experience by being able to make inde-

pendent decisions. Trusting lower level managers and giving them more independence results in a more enjoyable job environment and a higher level of morale at the National Forest level. Finally, as Project Spirit has demonstrated, if lower level managers are given fewer constraints, they may be more productive than if they are operating in a more centralized bureaucracy.

Other arguments against overly stressing the advantages of efficient analytical techniques are based on the very nature of our organization. We do not have a single bottom line profit criterion which can be maximized in the most efficient manner. Our goals and objectives are less clear; we operate in fuzzy decision environments. Only one of our multiple purposes is to operate efficiently. Archaeologists, biologists, and other professionals who are employed with the Agency, did not enter this line of work to maximize profit. Our diverse publics have a variety of goals and objectives which are difficult to consolidate into one index of efficiency.

A basic assumption of most mathematical modeling techniques is that relationships between inputs and outputs are certain; however, in the real world, measurements are difficult and data is often lacking. Our analytical techniques should not be anymore sophisticated than the data which they utilize.

In summary, a cost-benefit approach was applied to comparing the spreadsheet procedure with the mathematical programming approach to hierarchical multilevel modeling. We concluded that the spreadsheet approach was both the least-cost approach and the most effective alternative for meeting most of our criteria.

How Does the Hierarchical Spreadsheet Work?

Our basic assumption is that Forest Plan implementation is the focus of planning and decision-making at all levels of our organization. However, Forest Plans are mostly programmatic and guide expected accomplishments for 10 to 15 years. While Plans provide some scheduling information, little site specific and time specific information is provided. For example, Plans may contain proposals for a series of planned timber sales, nomination of a national historic trail, construction of recreation water and sanitation facilities, off-road vehicle closures, visual resource inventories, etc. However, many questions are not specifically answered in the Plan. For example, when during the planning period will these projects be scheduled? When will funds be requested? When will funds be received? How close to a full level of funding will be received? How will we keep track of our accomplishment? Which project should be highest priority? Can joint inventories be accomplished? Can joint projects be designed? Are projects in conflict with each other? Can projects be scheduled for greater efficiency? The 10-year implementation schedule developed on each Forest provides basic information for answering some of these questions.

Specific annual schedules must be prepared that mesh with the annual budget process and site specific project analysis.

THE NATIONAL FOREST PLAN IMPLEMENTATION AND MONITORING SPREADSHEET
DATE XX/XX/XX

FUND CODE	ACTIVITY CODE	COSTS IN M$	FY'87	'88	... '96
NFAF	FOREST	FIRE MGMNT			
		(item description)	..	..	..
		TOTAL M$	..	..	..
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
Continued for each of 43 standard cost categories.					
NFSW	FW22	WATERSHED IMPROVEMENT ACRES			
		(item description)	..	..	..
		TOTAL WATERSHED IMPV ACRES	..	..	..
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
		Continued for 50 items required by the Chief.			
		Continued for 24 tracking items required by the Regional Forester for land ethics and regional issues.			
		Continued for any items desired by Forest Supervisor.			

SUMMARY STATISTICS FOR REPORTING TO THE REGIONAL OFFICE

The TOTAL lines above are displayed here and reported to the Regional Office. While the Forest at its discretion can track individual items by additional detail such as by project, analysis area, management area, or Ranger District, the summary statistics portion of the spreadsheet is the only portion that is mailed to the Regional Office. This provides our total information needs for LMP monitoring, program development, budgeting, RPA, etc. We do not intend to go back to the Forest for additional information. Some right-hand-side statistics appear to the right of the '97 column which indicate the percent of planned goals which have been attained to date.

Figure 1.–Simplified schematic diagram of a forest's spreadsheet.

Progress toward Plan accomplishment must be tracked and evaluated. Scheduling changes must be recorded and impacts of budget deviations must be displayed. The need to change the Plan must be analyzed. The public must be informed.

Plan implementation schedules will be the basis for prioritizing work. They also will be the basis for eliminating lower level priorities.

An abbreviated schematic diagram of the implementation schedule is illustrated in figure 1. The FUND and ACTIVITY code columns on the left are standard NIR (National Information Requirement) codes which are used throughout the organization. Uniform and consistent codes are needed to avoid creating a Bureaucratic Tower of Babel in a multilevel organization.

The potential of goal programming as a decision support system was discussed earlier in this symposium by Larry Davis. A related topic, goal scheduling, is accomplished with the implementation spreadsheets. Goal scheduling has several components. They include:

1. reviewing the Plan,
2. setting goals,
3. writing out the goals,
4. charting progress in attaining the goals, and
5. evaluating results to date.

The exercise of scheduling out the Forest Plan has increased understanding of the Plan and commitment to it.

The individual Forest Plan implementation spreadsheet is a simple and effective tool. It will do more than anything else to facilitate understanding of the Plans by the public. The implementation schedule and the graphs which accompany it visually display the entire Forest Plan, and track accomplishment toward meeting planned goals and objectives.

Continued citizen participation is one of the critical aspects of monitoring Forest Plans. We will continue to seek public participation in Forest Plan implementation. The implementation schedule will be a primary tool to show the public what we have accomplished to date, and what remains to be accomplished during the Plan period.

It is important that the public as well as our managers know how successful our management programs are. The public can help us design better ways to correct problems if we begin to drift away from implementing our Forest Plans. We will develop a layman's guide to Forest Plan implementation which defines the implementation strategy in a concise and understandable way.

This will be published each year as an "annual report to our shareholders." This will summarize the results of Forest Plan implementation. It will show our normal accomplishments such as timber produced, forage grazed, etc. However, the unique thing about our report is that it will emphasize qualitative aspects of caring for the land--those items which are associated with land ethics. For example, figure 2 illustrates what we expect to happen to satisfactory watershed condition acres over the life of this first generation of Forest Plans. The information provided on each land ethic item will indicate

1. what is planned for the Plan period,
2. what has been accomplished to date, and
3. what remains to be accomplished over the remaining life of the Plan.

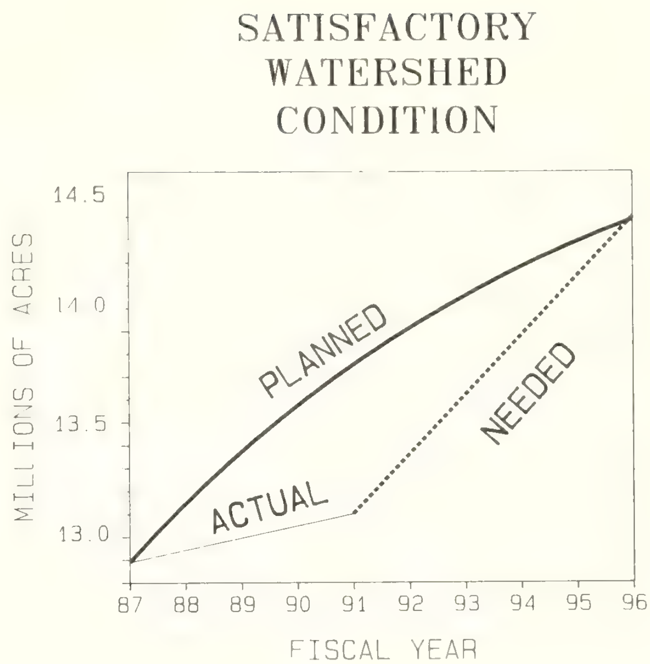

Figure 2.--An example of a land ethics graph.

Forest Plans delegate a large degree of discretion and responsibility to the Forest Supervisors for Plan implementation. The Regional Office role will shift appropriately from control to emphasize quality review. The spreadsheets will facilitate this move to a more decentralized organization.

The spreadsheets are living documents. They are constantly being updated at the Forest level to reflect new knowledge gained from monitoring, deviations between the planned schedule and accomplishments, as well as amendments and revisions to Forest Plans. At least twice a year, the Regional Office takes a snapshot of each Forest's spreadsheets in order to put together a regional photo album of the state of our forests at a given point in time. This constant update feature allows us to monitor the results of Forest Plan implementation, develop program proposals to submit to the Washington Office, allocate budgets and targets to the Forests, etc.

In contrast with our experience, a more sophisticated hierarchical analytical system either would not have been implemented in the first place, or would have been put on the shelf within a couple months. By using a simple, down-to-earth, user-friendly system, we have a hierarchical modeling system which truly can say, "I have been used."

In the introduction to this paper, the sixteen uses of the spreadsheet by Regional Office personnel were listed. Most of these applications have taken place in the past couple of months. We expect this simple frame of reference (or something similar) for Forest Plan implementation to continue to be used in the years ahead.

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Acknowledgments

I thank Corey Wong (Recreation and Lands Staff, Espanola Ranger District, Santa Fe National Forest) for reviewing an earlier draft of this paper, and introducing me to the world of hierarchical modeling within the Forest Service. Larry Leefers, Assistant Professor, Department of Forestry, East Lansing, Michigan also provided some valuable comments.

Design of a Resource Allocation Mechanism for Multiple Use Forest Planning

Gonzalo L. Paredes V.[1]

Abstract.--A method for implementing a systematic forest planning process is presented. The features that make hierarchical decomposition are explained. Recent developments in economic planning and management theory that should be incorporated into the design in order to overcome the shortcomings of the current planning experience are described.

The practice of planning in forest organizations, public, or private has become the focus of attention in recent years as the forest land base decreases and society values multiple outputs from the forest. It is also becoming apparent that the forest sciences, mainly forest economics and management, have not yet developed an appropriate and generalized framework for successful implementation in actual institutions. Where multiple-use forest planning and economic efficiency are institutionally requested, the modeling approaches currently undertaken have either increased problem complexity to levels beyond the comprehension of the managers, the public, and even the modelers themselves; or simplified it to levels where it no longer allows for efficient allocation decisions.

The above situation is evident in public agencies where timber, recreation, wildlife, water, and other nonmarket commodities have to be accounted for in the planning process. But in large private corporations the nonmarket concerns are often replaced by other pseudo-commodities such as cash flows, market share, financial ratios, and other externalities. The analogies are in many cases straightforward, thus the concepts discussed in this paper, although related to planning in a public agency, can be extended to private firms.

The purpose of this paper is to provide a theoretically sound framework to analyze planning issues recently brought up by the current experience of the USDA Forest Service, where an attempt to utilize a mathematical programming technique as a tool in the planning process has produced less than satisfactory results.

The concepts presented in the paper strongly rely on the use of duality theory embedded in the mathematical programming techniques commonly used in forest planning. As illustrated in Paredes and Brodie (1988a), the practice of forest planning can not neglect the concepts and the economic rationale embedded in mathematical programming commonly used in forest planning. The analysis of key forest policy issues can be illuminated if basic duality rules are observed. Also the linkage between stand- and forest-level planning can be established through duality concepts (Paredes and Brodie 1988b).

Next, we illustrate the characteristics that make multiple-use forest planning a large-scale task, and presents the main criticism to the currently, primal approach to forest planning implemented in many public and private forestry agencies.

Finally, it is necessary to describe some of the concepts from economic planning theory that have been absent in forest planning literature. During the last two decades interesting and practical results have been obtained in the design of resource allocation mechanisms to improve the economic efficiency of existing ones. It is self-evident that the implementation of a planning process will normally require more than the simple choice of a mathematical device in order to produce satisfactory results.

The fourth section describes a short-run resource allocation model for multiple-use forestry at a regional level. It describes a process within which local managers and regional managers interact with a language of production targets and shadow prices in an iterative process that, once implemented, can be conducted continuously. A general description on how the model addresses and solves the managerial efficiency problems currently present in planning processes is also given.

The Planning for Multiple Use of Forest Lands

The performance of a forest planning process has been traditionally viewed as dependent on, or conditioned by, the

[1]*Author was a Graduate Research Assistant, Department of Forest Management, Oregon State University. Currently he is Instructor, Forest Management Institute, Austral University, Valdivia, Chile.*

analytical model utilized. In describing analytical requirements for multiple-use forest planning Teeguarden (1987) points out that some of the "generic characteristics of the ideal analytical model...[are] the following key structural capabilities" (p.20): (1) simultaneous multi-resource land allocation, activity scheduling, and prescription selection analysis; (2) analysis of both spatial and temporal allocation problems, including the effect of policy constraints; (3) establishment and analysis of vertical linkages between forest, regional, and national levels; (4) establishment and analysis of horizontal linkages to other national forests and the private sector in a region; (5) economic efficiency analysis; and (6) economic and social impact analysis.

With all these requirements, in addition to others, multiple-use forest planning becomes a large-scale and complex task.

Simultaneous consideration of spatial and temporal relationships, externalities of timber production and vegetation manipulation, and production of non-market goods and services raises the complexity level beyond the limits of any single technique. Forestry literature reveals that the approach generally utilized to deal with these aspects has been to break down the problem in the sense that one requirement is addressed at a time. Then, the modeling technique is enlarged to account for that aspect, and finally its mathematical properties are studied in order to derive a numerical procedure that overcomes the computational burden of the previous enlargement.

Modeling in Forest Planning

Modeling efforts have been largely dominated by their focus on the dynamic nature of forest systems production. Issues such as forest regulation, long run sustained yield, and non-declining flow of timber are important and traditional concepts inherited from nineteenth century forestry in Europe. Foresters have to deal with them in forest modeling and planning processes. A survey by Reed (1986) presents many of the relevant approaches to account for the time dimension of forest planning. When the initial state of the forest does not present the equilibrium conditions for maximum sustained yield, binary search, the maximum principle, and linear programming have demonstrated their suitability to deal with the dynamic aspects of large scale forest planning.

Well known examples of linear dynamic models for forest planning are the works by Johnson and Scheurman (1977), Navon (1971), and a modeling scheme recently proposed by Reed and Errico (1986). The incorporation of time on forest resource allocation has an explosive effect on problem size. Without aggregation of time periods, problems soon become intractable within a linear programming approach as the number of stands or time periods increases. However, their linear formulation presents a well-defined staircase structure suggesting the use of decomposition techniques. The works by Berck and Bible (1984), Caswell and Rao (1974), Ericksson (1983), Hoganson and Rose (1984), Liittschwager and Tcheng (1967), Nazareth (1980), and Williams (1976) are some of the efforts along the lines of the Dantzig and Wolfe (1960) technique, to overcome the computational burden of large-scale harvest scheduling problems. Their focus has been on the computational aspects of using this technique when forest planning is enhanced with respect to the time dimension.

Forest modeling efforts were enhanced in the early 70's when it was realized that, to solve for the best use of forest land, not only a dynamic problem had to be solved, but also a spatial location problem in order to obtain meaningful and implementable land use decisions.

The first aspects to be identified as closely related to spatial dimensionality were those on transportation activities.

By observing that usually a slight increase in timber harvest costs, because of a shift in stand location, can be more than offset by reduction in transportation costs, Kirby (1973) initiated a modeling effort that demonstrated the advantages of simultaneously analyzing wildland resource management projects and their required road network. Kirby introduced a mixed integer programming (MIP) formulation, named Integrated Resource Planning Model (IRPM), to solve for an optimal performance of land use projects less transportation costs (including road construction) subject to management constraints and to temporal and spatial dependence between projects and access roads. Until then the U.S. Forest Service and private industries had been solving separate transportation plans for each land use project.

Global network analysis for all projects with shared access became a promising modeling approach for meaningful forest planning. The interest later tended to dissipate when researchers and practitioners realized that no algorithm with polynomially bounded execution time could be found to solve for the concave programming problem resulting from MIP models. The approach is therefore used in small size, short-run, planning problems.

In response to the proposal of MIP models for use in forest planning and because of their high computational requirements, planners in the U.S. Forest Service have incorporated very much the same features of Kirby's model into the LP-based FORPLAN system (Iverson and Alston 1986). Since the simplex code assumes continuous linearity on activities relationships, users have adopted a heuristic approach by rounding-off and/or redefining the projects that should correspond to integer variables but are treated as linear ones in the FORPLAN model. As is well known, this simplest heuristic to obtain integer solutions from an LP relaxation may result in large deviations from the true optimum to the MIP problem. Sessions (1985) and Weintraub (1978) implemented more elaborate heuristics.

It has been later demonstrated that the MIP approach can also be tailored to solve for other spatial aspects of multiple use land planning (Kirby et al. 1986), such as recreational uses, streamflows sedimentation, and wildlife habitats.

An alternative method to account for spatial relationships between stands has been developed by Bowes and Krutilla (1985) using dynamic programming to solve for multiple stands management with timber and non-market outputs.

The solution methods outlined above have all a common ingredient: their developers have attempted to solve as much as they can while using a single optimization technique. Furthermore, forest planning has been viewed as a single-level exercise as if every aspect of the decision process could be adequately addressed through a unique model. The results are formulations that tax either planning staff comprehension or computing capabilities. It is also now becoming clear that an undesired by-product of a single-level approach has been its inability to model the linkage to other agencies and to other decision making levels within the institution.

In light of the problems of practical forest planning, the idea of partitioning the planning process has recently grown up among forest managers. One of the catalytic elements has been the current experience of the planning process as conducted in the U.S. Forest Service in implementing the U.S. National Forest Management Act. A "rational-comprehensive multiple-use planning of the National Forest system" (Teeguarden 1987) to maximize a vaguely defined concept of "net public benefit" has been mandated to the agency. Then, the Forest Service has relied, as its "main analytical tool" (Russell 1987) on a computer code that permits formatting of raw data into a matrix input for a commercial Linear Programming code to solve the problem. Then this code (FORPLAN) tabulates and summarizes results (Johnson et al. 1986). The capability to automatically generate a system of linear equations that could then be processed and solved by the simplex algorithm has fascinated planners in the agency. As a result discussions on the planning process invariably shift into the analysis of the matrix generator/report writer, instead of the process itself.

The issue of coordination of the planning process with other public and private resource allocations has been recently raised as a major source of criticism in the National Forest planning process. It is often observed that the planning process does not link planning at the forest level, the Resource Planning Act (RPA) program, and the annual Budget process. As illustrated by Beuter and Iverson (1987) "the planning process is done in a vacuum" (p. 92).

The planning process has been also characterized as having the effect of shifting "power upward in the classically decentralized Forest Service...(thus limiting) on-the-ground testing of alternative analytical approaches to the forest planning problem" (Binkley 1987, p. 101). Hierarchical, or multi-level planning, is claimed as a necessary approach also by Dykstra (1987). Also Beuter (1984) and O'Toole (1987) have argued in favor of implementing a somehow decentralized management of land units in a "business-like" fashion.

Few contributions are found in forest literature on analytical models to address either decentralization or inter- and intra-institutional linkages. The economic ideas embedded in the decomposition method of Dantzig and Wolfe (1960) provide a solid analytical framework to managerial decentralization and give a protocol of messages to be implemented in hierarchically dependent management units to achieve optimal allocation decisions (Baumol and Fabian 1964). However, of the works utilizing the method, only Williams (1976) seems to capture the idea of the Dantzig and Wolfe routine and provides an interesting, but sketchy, description of decomposition as applied to an idealized hierarchical decision process in a public forest agency.

As an attempt to overcome the lack of coordination between regional and forest levels, Hof and Pickens (1987) propose a two-level model where the upper level solves an integer programming problem with discrete activities, each representing the choice of management plans developed by the local planning units.

This model is conceived as a non-iterative process that would allow the planning authority (the U.S. Forest Service) to overcome the inexistence of "an elaborate communication network and coordinating authority" (p. 247), and the difficulties of concurrent operation of the planning process at lower-level units.

Navon and Weintraub (1986) suggest also a heuristic to elaborate supply alternatives for "a few neighborhoods" in the decision or policy space of the wildland enterprise (p. 354). The procedure involves only one iteration between central authority and unit managers. These submit only one set of discrete proposals, covering all scenarios, to the center. Then returned back a message describing their production plan is returned back. It is not clear, however, how the center formulates constraints for the global integer program, and how these models are interpreted in terms of their economic efficiency. It is convenient to recall that the "nonlinear outputs and inputs" which are dealt with in steps 3 and 4 are typically those representing public goods and externalities of multiple-use forest management. The economic interpretation of such an integer program could yield meaningless prices for non-market commodities.

By implementing management plans selected from among discrete options it becomes extremely difficult to adjust the operations whenever the institution detects wide environmental fluctuations or actual variations in the values for parameters of the model. This can be illustrated by considering, for instance, a situation where the global IP calls for a recreation-oriented plan at unit A, and for timber specialization in unit B. An observed small change in constraint level of the global IP, allowing for a reduction in the minimum level of recreation requested, may translate into a dramatic shift to a discrete choice of reduced recreation in unit B, after the initial investments for a timber oriented plan have been undertaken. This undesired situation can be obviously overcome if enough discrete choices are included so that a "smooth" transition is allowed. The tradeoff in this case would be a further increase in size of the, already large, integer programming problem.

In terms of message exchanges, the procedure requires massive data transmitted between the center and the units, and forces the center to solve two large-scale problems.

Partitioning of the forest planning problem has also been attempted in the planning practice of public institutions. Mitchell et al. (1987) describe a procedure that sequentially solves: (1) a one-period "steady state" model to address spatial manage-

ment issues; (2) a "harvest scheduling" model to analyze the dynamic characteristics of the timber harvest flow; and (3) a "final model" where activities are input according to selections made in the previous steps and modifications by operations personnel. The implementation of this procedure allows a heuristic reduction in the number of activities to be considered in the final planning model.

The planning process is still centralized at the forest level; however, it allows for certain involvement of the lower decision making level. In general, this procedure represents one of the many attempts that can be found in the practice of forest planning in order to break down the problem to actual comprehension levels.

As observed from the multi-stage modeling approaches discussed above, the driving concern in their development has been the search for computationally feasible methods for a large-scale problem. The limitations arise as a result of including, at the same resolution level, decision variables and parameters that correspond to different types of management participation. Reliance on a single mathematical programming method, without exploiting the advantages of specialized techniques, also characterizes the reported planning procedures.

This mindset has been pervasive in forest planning, and is well reflected throughout the experience of the U.S. Forest Service in implementing a "rational-comprehensive multiple-use planning of the National Forest system" (Teeguarden 1987, p. 20) to maximize a non-defined Net Public Benefit.

In failing to analytically account for many of the "key structural capabilities" enumerated early in this section, forest economists often rely on the literal wording of the relevant legal mandates, or on the properties of the analytical tool readily available. Teeguarden (1987), for instance, points out that "cumulative effects within a forest and across different forests within a region are not explicitly mentioned in NFMA or the Regulations" (p. 21), as if these were a recent issue not already revealed by, or implicit in, the overriding mandate of economic efficiency or maximization of "net public benefit," an ambiguous name for "social welfare."

With respect to reliance on the available analytical tool, the common belief is that with "the selection of FORPLAN as the primary analysis tool...the National Forests chose the pursuit of economic efficiency in their forest planning model over the detailed simulation of environmental effects" (Johnson 1987, p. 46). Economic efficiency is, however, granted by market equilibrium and welfare allocations beyond the use of any generic mathematical programming technique.

As illustrated in the previous paragraphs, the recent practice of forest economics and planning have been confounded by a number of policy issues and societal concerns on the management of public forest lands. Mathematical programming and computers have often been viewed as salvation devices and currently many state their hope on even more computing power or faster techniques. Instead, it is proposed here that the practice of forest planning could first recast some of the recent developments in management and economic theory. The next Section describes some of them.

A Strategic Allocation Model for a Forest Region

In multiple-use land management the need for a decentralized, hierarchical approach seems to be unquestioned because of the technical, ecological, and economic characteristics of the forest ecosystem production process. The issue is again raised now that the U.S. Forest Service has extensively implemented an uncoordinated, primal, centralized, and single-level planning process.

The relevant questions are: how to define the levels of control within an organization; how many are necessary, and how are they linked? A proposition for spatial hierarchies--nation, region, forest, and district--would be necessarily restrictive if a single planning horizon were attached to each level. Temporal hierarchy must also be defined at each level; at a national level, for example, budget allocations are conducted on a yearly basis, while another decision making process allocates long-term research and development projects.

Multi-level, multi-type decompositions of large-scale systems, formalized since the early 70's in systems engineering (Haimes 1982), result in multifarious subsystems that can be identified as being potentially viable or economically efficient (Beer 1979).

Having the above in mind, the following discussion on a forest resource allocation process focuses on a short-run regional economy. Short-run is here understood as the period of time where major investments relevant to a regional level are assumed as given. Normally a period of 5 years is considered appropriate.

Inherent in the design of a resource allocation process is the problem of representing society's preferences among alternative states of the economy, so that the problem can be stated as finding the most preferred feasible state. Usually societal preferences for public forest management are vaguely presented with expressions as "maximum social benefit" or "maximum net public benefit" without explicitly mentioning, but relying upon some measures of economic efficiency and equity.

For a meaningful construction of an objective function representing societal preferences it is necessary to rely on the concept of tradeoffs between variables. The evaluation of these is greatly simplified if the objective function can be assumed to be additively separable, i.e., it can be represented in the form

$$U(y) = \Sigma^{G}_{g=1} U(y_g) \qquad [1]$$

where $U(y)$ is the total utility function and $U(y_g)$ is the separable utility of consuming the group of variables represented by y_g.

At a regional level it is possible to assume that this assumption holds in multiple-use planning. The commodity bundle can be separated into groups of homogeneous commodities. This is facilitated if (i) variables are made explicit in the input/output decision space, and (ii) constraints, if any, on variables should

be explicit. The effect of these conditions is to avoid hidden pre-allocations of resources, and the construction of variables with embedded, not recognizable, and not available constraints.

Paredes and Brodie (1988a) demonstrate that when these conditions are met, the objective function for the multiple-use forest model can be additively separated into different commodity groups:

$$U(\mathbf{y}) = U(\mathbf{y}_m) + U(\mathbf{y}_n) \qquad [2]$$

where $\mathbf{y}_m$ and $\mathbf{y}_n$ are, respectively, the vectors of market and nonmarket commodities. Since output levels for nonmarket goods are usually modeled as right-hand side allocations,

$$U(\mathbf{y}_n) = \mu_n \bullet \mathbf{y}_n \qquad [3]$$

where μ_n is the vector of shadow prices associated with an allocation of $\mathbf{y}_n$.

Additionally, this modeling approach for a separable objective function satisfies the requirements for a homogeneous scaling among the groups of variables. It is known, from duality theory, that shadow prices in a general linear programming context are expressed in the same measure units as the primal objective function, i.e.,

$$\mu_n = \delta U(\bullet)/\delta y \qquad [4]$$

implies that the measure units of $\mu_n \bullet \mathbf{y}_n$ are consistent with those of $U(\mathbf{y}_m)$.

By expressing all valuation units in the allocation problem in terms of $U(\mathbf{y}_m)$, the units of measure for these become the numeraire of the process. Since a close approximation to social welfare is desired, the numeraire has to be chosen accordingly. The ideas presented in the previous section suggest that a desirable property would be a resemblance of the process to a competitive market.

At the same time, it is convenient to recall here that one of the requisites forest managers and economists are recently requiring from an allocation mechanism, refers to its capability to account for cumulative effects across production units on a regional basis (Teeguarden 1987).

Both requirements are implicitly satisfied by Samuelson's "net social payoff" concept to solve for multimarket equilibrium. Even though Samuelson (1952) did not imply any social welfare significance to the net social payoff magnitudes, it has been later demonstrated by Willig (1976) that the use of consumer's surplus magnitudes provides a good approximation to the appropriate welfare measures. Willig demonstrates that both compensating and equivalent income variations are accounted for in the consumer's surplus.

Adding to the formalization of net social payoff concept, Smith (1963) demonstrated that the dual of Samuelson's spatial equilibrium problem corresponds to rent minimization of production factors.

The use of net social payoff as the numeraire in the objective function at the regional level provides an interesting and, more important, implementable measure of social welfare to drive the allocation process.

Required elements for a net social payoff function are an inverse form of demand function for each demand center in the region. These functions are econometrically derived having the general form:

$$\mathbf{P}_c = Dc(\mathbf{y}_c) \qquad [5]$$

where $\mathbf{P}_c$ is the per unit price paid at demand center c for commodity quantities traded at that location, $\mathbf{y}_c$.

The supply functions are provided either by parametric programming for those production units "controlled" by the process, as illustrated by Paredes and Brodie (1988a) in a forest-level context, or by behavior simulation or econometric analysis for those units beyond the institutional limits. Typically a supply function will have the form:

$$\mathbf{P}_p = S_p(\mathbf{y}_p) \qquad [6]$$

where $\mathbf{P}_p$ is the per-unit marginal cost of producing the set of commodities, at level $\mathbf{y}_p$ at the production unit p.

Commodity flows are modeled through specific variables y_{pc} describing the bundle of commodities flowing from production center p to market location c. The associated transportation costs are generally assumed linear and described through the coefficients t_{pc}.

The objective function then takes the form:

$$\max\ U = \sum_c \int_0^{u_c} D_c(\tau_c)\,d\tau_c - \sum_p \int_0^{w_p} S_p(\tau_p)\,d\tau_p - \sum_{p,c} t_{pc} y_{pc} \qquad [7]$$

subject to

$$u_c \leq \Sigma_p y_{pc}, \qquad \text{for all c} \qquad [8]$$

$$w_p \geq \Sigma_c y_{pc}, \qquad \text{for all p} \qquad [9]$$

where equation [8] bounds the total amount demanded at the c-th market location, and equation [9] bounds the amount of commodity supplied at the production unit p. The τ's are dummy integration variables. Equation [7] accounts to the net social payoff as the consumers' surplus less producers' surplus and transportation costs.

An objective function formulated in this way, at a regional level, addresses a topic often neglected in forest planning models, accounting transportation costs as endogenous variables. This can provide an alternative to current timber valuation methods based on a stumpage concept. While the flat stumpage approach may be appropriate for small owners, it is necessarily restrictive in a forest/regional context where the definitive impact of the main cost item (hauling) is dependent on market location. At this level market destination for timber can not be assumed away.

The same rationale applies for those forms of recreation where travel cost methods provide estimates of consumer's willingness-to-pay and therefore approximate the impact of recreation outputs into social welfare. An objective function with resolution for recreation demand centers and recreation supply units, linked through the actual transportation network, could vastly improve on current allocation methods.

Similar functional forms for the objective have been previously used in forestry planning by Greber and Wisdom (1985), although they focus on interactions in roundwood markets only, and transportation costs are not endogenous to the model. A closer form has been utilized by Fowler and Nautiyal (1986) for land allocation to agricultural, timber, mining, urban, and recreational uses. In this model, production units are defined as grid cells on a map. Both models are single-level.

The construction of an objective function which, at the regional level, approximates society's preferences on economic welfare states, provides a solid base to decompose the planning procedure to lower hierarchical levels. This achieves Kantorovich's "system of information, accounting and economic indexes and stimuli" mechanisms which makes local managers to select socially optimal actions.

Production levels and flows are technically constrained by the system of equations relating outputs and inputs for each local production unit. The following equations describe, respectively, those constraints:

$$\mathbf{w}_p - \Sigma_p T_p(\mathbf{x}_p) = \mathbf{0}, \quad \text{for all p} \qquad [10]$$

$$\Sigma_p \mathbf{x}_p \leq \mathbf{b} \qquad [11]$$

where $T_p(\mathbf{x}_p)$ is the production function at unit p that describes the technological relationships between inputs, $\mathbf{x}_p$, and outputs, $\mathbf{w}_p$. In a strict sense, equation [10] is redundant since the relevant information on output levels is already embedded in the objective function's term for the producer's surplus. Equation [10] is included here only for completeness when illustrating, later, the operational aspects of the model.

The symbol **b** represents the vector of initial resource endowments of the regional economy. It describes both the resource base of each production unit (land base and vegetation cover, for example) that can not be changed within the planning period, and the resources (public and private) available to the regional economy which will be consumed by the local units.

As described above, the model still does not provide an explicit treatment for production/consumption of those commodities that can not be treated with information provided by actual markets. The presence of externalities, the production impacts on public goods, and the effect of economies/diseconomies of scale are some of the "cumulative effects," as usually identified in recent forestry literature, that need to be explicitly accounted for. These are the issues, varying in emphasis from one region to another, that generally refer to the effects of policy requirements such as long-term sustained yield, wildlife habitat protection, species diversity, roadless areas conservation, and others.

These constraints are represented, generically, by the form

$$\Sigma_p g_p(\mathbf{w}_p, \mathbf{x}_p) \geq \mathbf{h} \qquad [12]$$

where the function $g(\bullet)$ describes the technical relationships, linear or nonlinear, between market commodities/resources and the nonmarket ones. The vector **h** describes the levels requested for nonmarket commodities. The convention that goods are desirable is followed here; for example, an element of **h** would request a minimum of the commodity "clear water," instead of constraining the maximum of "water pollution." So instead of **h** constraining, for example, water pollution requests a minimum level of clean water.

The incorporation of these outputs at a regional level is consistent with current practices in public forestry, e.g., the RPA Program of the U.S. Forest Service. Furthermore, it reduces the possibility of non-convexities that may occur associated with externalities at the forest level.

It needs however be recalled that the **h**'s are still regarded as decision variables. The regional planning authority determines their optimal values trying to emulate a Lindahl equilibrium for public goods. This will be discussed later.

The problem is therefore to maximize [7] subject to equations [8] to [12] and the usual nonnegativity constraints of the arguments **x**, and **w**.

A "one-pass" solution of the planning problem presented would be a formidable task. Each local unit would need transfer to the center the information described by the $T_p(\bullet)$ and $g_p(\bullet)$ functions. Even if the model solves for short-run allocation and it has unlimited computing facility, the problems of transferring local expertise would render the "one-pass" approach impractical. Decentralization now comes to the rescue.

For an understanding of the procedure's economics a characterization of the optimality conditions is presented.

To simplify notation let

$$R_c = \int_0^{u_c} D_c(\tau_c)\, d\tau_c \qquad [13]$$

$$R_p = \int_0^{w_p} S_p(\tau_p)\, d\tau_p \qquad [14]$$

then the Lagrangian function associated with the problem can be written:

$$\begin{aligned} L = \Sigma_c R_c - \Sigma_p R_p - \Sigma_{pc} t_{pc} y_{pc} \; & + \Sigma_c \sigma_c[\Sigma_p y_{pc} - u_c] \\ & + \Sigma_p \mu_p[w_p - \Sigma_c y_{pc}] \\ & + \pi[\mathbf{b} - \Sigma_p \mathbf{x}_p] \\ & + \Theta[\Sigma_p g_p(w,x) - \mathbf{h}] \end{aligned} \qquad [15]$$

where σ, μ, π, and Θ are dual multipliers.

The Kuhn-Tucker conditions for optimality explain the economic rationale of the allocation process. At the demand centers, the total level of traded commodity, u_c, satisfies the following conditions:

$$u_c \geq 0,$$

$$m_c - \sigma_c \leq 0$$

$$u_c[m_c - \sigma_c] = 0, \quad \text{for all c} \quad [16]$$

where m_c is the total consumers' willingness to pay for a consumption level u_c at demand center c, and σ_c is the imputed value of the commodity delivered at the demand center. These are usually called regional consumer equilibrium conditions and state that, for positive levels of consumption, the price paid at the market equals the imputed cost of producing the commodity and transporting it to market at c.

Transportation decisions, from production unit p to market c, satisfy:

$$y_{pc} \geq 0$$

$$-t_{pc} + \sigma_c - \mu_p \leq 0$$

$$y_{pc}[-t_{pc} + \sigma_c - \mu_p] = 0, \quad \text{for all p, c} \quad [17]$$

These conditions regulate the flow of commodities across the region. They state that a commodity is hauled, $y_{pc} \geq 0$, if its transport cost, t_{pc}, does not exceed the price differential between its imputed values at production unit, μ_p, and at demand location, σ_c. These conditions are usually referred to as locational price equilibrium conditions.

The optimal production level at unit p, w_p is determined with the following conditions:

$$w_p \geq 0$$

$$-m_p + \mu_p + \Theta \bullet \delta g_p(\bullet)/\delta w_p \leq 0$$

$$w_p[-m_p + \mu_p + \Theta \bullet \delta g_p(\bullet)/\delta w_p] = 0, \text{ for all p} \quad [18]$$

where m_p is the marginal cost of the commodity at the production unit p, where m_p is evaluated with the technological constraint in equation [10]. These are called the supplier's equilibrium conditions and state that a commodity is produced ($w_p > 0$) up to the level where its imputed value, m_p, equals the market value of the output, μ_p, at p, plus the value of its marginal impact in the production of non-market outputs, $\Theta \bullet \delta g_p(\bullet)/\delta w_p$.

The optimal use of resources, x_p, is specified by:

$$x_p \geq 0$$

$$\mu_p \bullet \delta T_p(x_p)/\delta x_p + \Theta \bullet \delta g_p(\bullet)/\delta x_p - \pi \leq 0$$

$$x_p[\mu_p \bullet \delta T_p(x_p)/\delta x_p + \Theta \bullet \delta g_p(\bullet)/\delta x_p - \pi] = 0,$$

$$\text{for all p} \quad [19]$$

where π is the marginal value of production factors. These conditions state that resources are consumed up to the level where the marginal value of the resource is completely allocated among its marginal value impacts on the production of market, $\mu_p \bullet \delta T_p(x_p)/\delta x_p$, and non-market commodities, $\delta g_p(\bullet)/\delta x_p$.

The following are the market prices equilibrium conditions. They regulate commodities and resources valuations to avoid excess demand or excess supply possibilities.

$$\sigma_c \geq 0, \Sigma_p y_{pc} - u_c \geq 0$$

$$\sigma_c[\Sigma_p y_{pc} - u_c] = 0, \quad \text{for all c} \quad [20]$$

$$\mu_p \geq 0, w_p - \Sigma_c y_{pc} \geq 0$$

$$\mu_p[w_p - \Sigma_c y_{pc}] = 0, \quad \text{for all p} \quad [21]$$

$$\pi \geq 0, \mathbf{b} - \Sigma_p \mathbf{x}_p \geq 0$$

$$\pi[\mathbf{b} - \Sigma_p \mathbf{x}_p] = 0, \quad [22]$$

$$\Theta \geq 0, \Sigma_p g_p(w,x) - \mathbf{h} \geq 0$$

$$\Theta[\Sigma_p g_p(w,x) - \mathbf{h}] = 0 \quad [23]$$

The conditions in [20] and [21] determine, respectively, the consumers' and producers' behavior when facing positive prices and excess supply or demand for their commodities.

Conditions specified in [22] determine the pricing rules for resource consumed in production. Conditions in [23] guide the units' decisions on expansion of the production level of non-market outputs according to the price offered by the center.

A local manager would seek to allocate his inputs, $\mathbf{x}_p$, so as to maximize his total profits from market commodities, at prices μ_p, and from those nonmarket commodities that the center regulates, at prices Θ. Local managers solve the problem:

$$\underset{\{x_p, w_p\}}{\text{maximize}} \; \mu_p w_p + \Theta \bullet g_p(w_p, x_p) \quad [24]$$

subject to

$$w_p - T_p(x_p) = 0 \quad [25]$$

$$\mathbf{x}_p \leq b_p \quad [26]$$

$$x_p, w_p \geq 0$$

given μ_p, Θ, and b_p.

The corresponding Lagrangian to this problem is:

$$L_p = \mu_p w_p + \Theta \bullet g_p(w_p, x_p)$$

$$- \Phi_p \bullet [w_p - T_p(x_p)] + \pi_p \bullet [b_p - x_p] \quad [27]$$

Conditions for an optimum to the local manager problem are given by:

$$w_p \geq 0, \mu_p + \Theta \bullet g_p(w_p, x_p) - \Phi_p \leq 0$$

$$w_p[\mu_p + \Theta \bullet g_p(w_p, x_p) - \Phi_p] = 0 \quad [28]$$

$$x_p \geq 0,\ \Theta \cdot \delta g_p(\cdot)/\delta x_p + \Phi_p \cdot \delta T_p(x_p)/\delta x_p - \pi \leq 0$$

$$x_p\,[\Theta \cdot \delta g_p(\cdot)/\delta x_p + \Phi_p \cdot \delta T_p(x_p)/\delta x_p - \pi] = 0 \quad [29]$$

According to the definitions given in the regional problem formulation Φ_p is exactly equal to m_p. Thus the optimality conditions for a local manager, in equations [28] and [29], are equivalent to those in [18] and [19] for the global regional problem.

This clearly shows that if the center has available the correct values for μ_p, for all p, and those for Θ, then it could provide that information to the local managers and they would allocate resources and production in a socially optimal way. Alternatively, the center could set quotas on input or outputs for each firm following the ideas of Heal's quantity-guided procedure.

The regional manager's problem, after the firms have provided information on their output levels for market commodities, w_p, and their resources usage, x_p, can be stated as:

$$\max U = \Sigma_c R_c - \Sigma_c t_{pc} y_{pc} - m_p w_p - \pi \cdot [\Sigma_p x_p]$$

$$+ \Theta \cdot [\Sigma_p g_p(w_p, x_p)] \quad [30]$$

subject to

$$u_c \leq \Sigma_p y_{pc} \quad \text{for all c} \quad [31]$$

$$w_p \geq \Sigma_c y_{pc} \quad \text{for all p} \quad [32]$$

where equation [30] describes the center allocating consumption of the private commodities to maximize the difference between consumers surplus, $\Sigma_c R_c$, plus the social value of the nonmarket commodities, $\Theta \cdot [\Sigma_p g_p(w_p,x_p)]$, and the costs of transportation from production to consumption centers, $\Sigma_c t_{pc} y_{pc}$, plus production costs, $m_p w_p$, and the costs of resources utilized, $\pi \cdot [\Sigma_p x_p]$.

With optimality conditions given by:

$$y_{pc} \geq 0,\ -t_{pc} - \sigma_c + \mu_p \leq 0$$

$$y_{pc}\,[\,-t_{pc} - \sigma_c + \mu_p] = 0 \quad [33]$$

$$u_c \geq 0,\ m_c - \sigma_c \leq 0$$

$$u_c[m_c - \sigma_c] = 0 \quad [34]$$

which are equivalent to those given in [16] and [17] for the global regional problem.

As observed, the multiple-use forest planning problem for a regional economy is decomposable into decisions corresponding to a regional planning bureau and those associated to local unit managers. The language of the solution mechanism can incorporate either price or quota messages, or both. By letting each local manager adjust their input and output levels under his control according to the price messages received from the center, the problem is solved as in the Lange-Arrow-Hurwicz routine described in the previous section. In this case, the center would adjust its price messages proportionally to the excess demands at the commodities and resources markets. Such a routine is informationally efficient and results in Pareto-efficient allocations. However, a drawback in applying it is that the size of the problem would require to terminate the process after a finite number of iterations, possibly without ever reaching a feasible allocation.

Alternatively the problem can be solved with a price-guided routine where the center adjusts production quotas or resource consumption among local units according to their social marginal cost or to their value marginal product, respectively, as in Heal (1969). It can also be solved with a mixed price-quantity procedure as the one described by Heal (1971). These methods would guarantee a sequence of feasible solution with a monotonically increasing value of the objective function.

The selection of an iterative procedure to solve for the regional problem goes beyond the relevant scope of this analysis. The approach to planning process adopted here views it as a continuous decision making process that detects and evaluates environmental variations and, if necessary, adjusts actual operations to achieve the new equilibrium state. Therefore, each opportunity the model is solved only a few iterations become necessary to reach the new optimum. This is the property called homeostasis that characterizes optimally designed systems (Arrow and Hurwicz 1960, Beer 1972). A huge planning effort undertaken periodically every 5 or 10 years, as currently done in many forest institutions, is no longer necessary. The institution has a permanently actualized model of the planning problem.

Nevertheless, computational efficiency considerations are still important for the set-up stage of such a planning procedure, particularly when current output levels and market values are distant from the equilibrium values.

The selection of an iterative routine for the planning model just presented must also consider explicitly the particular characteristics of the resources and the nonmarket commodities represented in **b** and **h**, respectively.

Some of the resources in **b** are inherent to each local unit, such as the land base or the capacity of the internal transportation infrastructure. The central authority would benefit from the knowledge of the associated social value of these resources, as reported by π_b, to allocate the regional budget on, for example, virtual expansions of the land base through coordination with state and private lands, or construction of transportation facilities.

Other elements in **b** describe regional resources that are allocated among competing units. The annual budget is the typical example. Budget allocations are easily handled by the central authority through a quota mechanism where budgets are adjusted according to its relative social marginal productivity in each local unit. Thus each unit is required to inform its budget requirement as well as the marginal productivity of this input.

Further, some resources in **b** have the characteristics of public goods, from a local manager standpoint. The center supplies the commodity up to the level where its marginal social cost equals the sum, over all local units, of its marginal produc-

tivity effect on the market goods, $\delta T(\bullet)/\delta b$, times the marginal social value, μ_p, of the firm's output. In other words, the social value of an increment in supply of the public commodity equals the sum, over all firms, of its opportunity values if these are evaluated at shadow prices. This is clearly the case of budget allocations to fire prevention and protection systems, pest control, and research and development programs. At equilibrium for these commodities it is observed that the amount of the good demanded from each unit equals the amount supplied and, simultaneously, the marginal cost of supplying it equals the sum, over firms, of its marginal value.

For the nonmarket commodities accounted for in **h** the center does not have available an exact estimate of the society's willingness-to-pay curve, but only a crude estimate for the range of such values. Many of these commodities are typically public goods in the classical sense: protection of endangered species, ecosystem preservation, habitat diversity. In these cases, the center should price commodities such that the accumulated reactions of all firms result in an output level with opportunity cost equal to the total society's willingness-to-pay. Here the role of the center is to achieve, through a pricing mechanism, an output level that is politically acceptable to society.

At any instant, the local units allocate their resources and scheduled their outputs mix and levels such that they maximize revenues. If the prices, set by the center for the nonmarket commodities, are socially correct, then the firms will automatically allocate at the optimum for the whole economy.

Summary

In the paper we have tried to illustrate, respectively, the current approaches to forest planning and their shortcomings, the recent developments in the theory of economic analysis and management, and a design of a resource allocation model for multiple-use forest planning at the regional level.

Resolution of the conflicts raised by competing uses of the forest land require the design of resource allocation mechanisms that provide managers and interest groups with a tidy and consistent picture of the values associated to each allocation option. As a public manager once stated with respect to legislation and economics: "We need more one-armed economists who won't be able to say, 'but, on the other hand'..." (cited by Miles 1986, p. 46).

The developments in economic analysis (Hurwicz 1972) and the findings of managerial cybernetics (Beer 1972, 1979) during the last decades provide the tools required to address the complex issues of multiple-use forest management that past and current reliance on both orthodox planning concepts and generic mathematical programming tools have failed to solve.

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An Algorithm for Writing Adjacency Constraints Efficiently in Linear Programming Models

B. J. Meneghin, M. W. Kirby, and J. G. Jones

Abstract.--Land allocation and harvest scheduling linear programming models used for small area planning often must contain large numbers of constraints that restrict activities on adjacent management units. Minimizing the number of constraints required can reduce solution times and allow larger areas to be modelled when faced with software limitations on model size. This paper presents an algorithm for efficiently writing adjacency constraints in linear programming models. The approach, which combines multiple adjacency restrictions into one constraint, typically results in less than half the constraints required by the adjacency constraint formulations commonly used in the past.

As forest management planning moves from the strategic to the operational level, the nature of linear programming (LP) models used in planning analysis changes dramatically. At the operational level of planning, models must contain much more spatial detail because activities and environmental responses must be site specific. This means that the decision variables should correspond to management activities for small contiguous units of land so that model formulations can represent the geographic location and spatial arrangement of activities.

Modelling spatial relationships is important for wildlife habitat management (Thomas et al. 1979) and for restricting sediment production for the protection of fisheries. Models used to simultaneously analyze transportation networks and land management activities must also represent the spatial relationships between the transportation network and the land management units. Also, policies that limit the size of contiguous openings require restrictions on clearcutting activities on adjacent management units.

For each of these examples, modelling the spatial relationships is done through some type of constraint. Mealey and others (1982) described the use of dispersion constraints to model the distribution of wildlife habitat. Transportation models require constraint rows to prevent nonsensical solutions which allow timber harvesting before access road construction (Kirby et al. 1980). Finally, restrictions on activities that occur on adjacent management units are modelled by using adjacency constraints. These constraints restrict the selection of decision variables for mutually exclusive management activities on adjacent management units.

Clearly, the price of spatial specificity in an LP model is increased model size for the area being modelled. Dividing a study area into many small, discrete units adds to the number of decision variables and representing spatial relationships between these variables requires additional constraint rows. Operational models often have as many constraints as variables (Jones et al. 1986). Computer resources required to solve LP models increase rapidly with model size and in particular with the number of constraints. Furthermore, in practice, problem size is usually limited by the number of constraints rather than the number of variables. Reducing the number of constraints is therefore important.

Adjacency constraints are a common constraint that have the potential to add a large number of rows to an LP model. For example, Thompson et al. (1973) found 53 common boundaries between 66 stands on the Pocomoke State Forest in Maryland. Their 12-period model required 10 constraints for each pair of adjacent stands for a total of 530 adjacency constraints. This paper will focus on a method of formulating adjacency constraints that will require writing significantly fewer constraints than conventional methods. We will describe an algorithm that will be useful in automating the process of writing adjacency constraints for planning models.

The authors are respectively Forester, Land Management Planning, USDA Forest Service; Operations Research Analyst, Management Sciences Staff, USDA Forest Service and Research Forester, Intermountain Research Station, USDA Forest Service.

Conventional Adjacency Constraint Formulation

Operational models for project-level decision making are often formulated as integer or mixed integer (MIP) models. Specific projects such as construction of a road or clearcutting a delineated stand become decision variables that will take on values of 1 or 0; build or do not build, cut or do not cut. When model sizes become too large to be solved by commercial MIP packages, they can be formulated as LP models with the 0-1 variables formulated as continuous variables with an upper bound of 1. Heuristic procedures such as those developed by Weintraub (1982) can then be used to achieve an integer solution. In this paper we assume that decision variables represent management activities on discrete contiguous areas of land that can only take on values of 0 or 1.

We begin our discussion of conventional formulations with a single period problem with one management alternative per unit. Each management activity is represented by the variable X_i which takes on the value of 1 if the management activity is chosen for unit i and 0 if not chosen. In conventional formulations, mutually exclusive constraints are written for each pair of units. For example, the pairwise formulation for the units in figure 1(b) would be:

$$X_1 + X_2 \leq 1$$
$$X_2 + X_3 \leq 1$$
$$X_2 + X_3 \leq 1$$

The difficulty with the conventional pairwise approach is that it requires a large number of constraints for realistic problems. For example, a simple 49-unit square checkerboard (7 rows and 7 columns) has 84 distinct adjacency conditions, and hence would require 84 pairwise constraints like those above.

Formulations for Reducing the Number of Constraints

Fewer constraints are needed if more than two adjacency conditions are represented in a single constraint. Writing such "combining" constraints can be done in a two step process.

Type 1 Inequalities

The first step is to write what we call Type 1 inequalities. The general form of these inequalities is as follows:

$$\sum_{i \varepsilon A} X_i \leq 1 \qquad [1]$$

This constraint represents the mutually exclusive conditions for a group of units such that each unit in group A is adjacent to each other unit in that group. There are three types of spatial arrangements that meet this condition. The simplest, already mentioned, is the adjacency pair illustrated in figure 1(a). Figure 1(b) illustrates the second arrangement, the adjacency triplet. The final arrangement is the quadruplet, shown in figure 1(c).

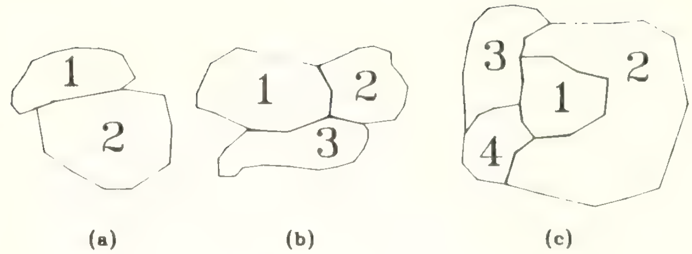


Figure 1.--The three spatial patterns that can be represented with Type 1 adjacency constraints: the pair (a), the triplet (b) and the quadruplet (c).

We will refer to these spatial arrangements as Type 1 patterns. The constraints for these three cases for one time period and one management alternative take the form of equation [1] as follows:

Pair: $X_1 + X_2 \leq 1$

Triplet: $X_1 + X_2 + X_3 \leq 1$

Quadruplet: $X_1 + X_2 + X_3 + X_4 \leq 1$

To represent the adjacency conditions in these three arrangements with pairwise constraints would require 10 constraints (1 for the pair, 3 for the triplet and 6 for the quadruplet).

Type 2 Inequalities

Often there are opportunities to further reduce the number of constraints by means of a second type of combining formulation, called Type 2 inequalities. A single Type 2 inequality can be substituted for a set of Type 1 inequalities, R, under the following conditions:

<u>If:</u>

$$\text{Sum}_{i \varepsilon E} X_i + X_{i \varepsilon P} \leq 1 \qquad [2]$$

and:

$$\text{Sum}_{i \varepsilon E} X_i + \text{Sum}_{i \varepsilon G} X_i \leq 1 \qquad [3]$$

and:

$E \cap P \cap G = \emptyset$ (E intersect P intersect G equals null set)

Then: the inequalities in Set R can be combined into a single Type 2 inequality of the following form:

$$(2r-1)\text{Sum}_{i \varepsilon E} X_i + \text{Sum}_{i \varepsilon P} X_i + (r)\ \text{Sum}_{i \varepsilon G} X_i \leq (2r-1) \qquad [4]$$

Where:

Set R = the Type 1 inequalities meeting the conditions set forth by equations [2] and [3]

r = the number of Type 1 inequalities in Set R

Set E = projects that are present in each of the inequalities in set R

Set P = projects that are present in only one inequality in set R

Set G = projects that are members of a group present in only one inequality in set R

The adjacency relationships between the five units in figure 2(b) can be represented by three Type 1 constraints as follows:

$$X_1 + X_2 + X_3 \leq 1 \qquad [5]$$

$$X_3 + X_4 \leq 1 \qquad [6]$$

$$X_3 + X_5 \leq 1 \qquad [7]$$

These three inequalities meet all the conditions to allow them to be combined into one Type 2 inequality. First, there is at least one variable, X_3, that is present in all three Type 1 constraints. This variable makes up set E. The remaining variables in inequality [5], X_1 and X_2, satisfy the conditions of set G and equation [3]. The remaining variables of inequalities [6] and [7] individually meet the conditions of set P and equation [2]. Therefore, inequalities [5], [6] and [7] form a set R that can be combined into one Type 2 inequality according to the general form of equation [4]:

$$5(X_3) + X_4 + X_5 + 3(X_1) + 3(X_2) \leq 5 \qquad [8]$$

The general form of equation [4] represents the six basic combinations of the three Type 1 patterns shown in figure 1. These combinations, referred to as Type 2 patterns are:

1. Triplet combined with m Pairs, shown in figure 2
2. Quadruplet combined with m Pairs, shown in figure 3
3 Quadruplet combined with m Triplets, shown in figure 4
4 m Pairs combined, shown in figure 5
5. m Triplets combined, shown in figure 6
6. m Quadruplets combined, shown in figure 7

An Algorithm for Combining Adjacency Constraint Rows

This section presents an algorithm for writing a reduced set of adjacency constraints that represent all of the adjacency relationships between a group of units. The algorithm consists of two steps: in step 1 the Type 1 inequalities are identified and in step 2 they are combined into Type 2 inequalities.

Identifying Type 1 Patterns

The first step is to identify a set of Type 1 inequalities that represents the adjacency relationships for all the units in an area. This is accomplished by creating an adjacency matrix with a row and column for each unit. If two units are adjacent, the intersections of their respective rows and columns are marked, otherwise the cells remain blank. Since the completed matrix is symmetrical along the principal diagonal, only half of the matrix is used.

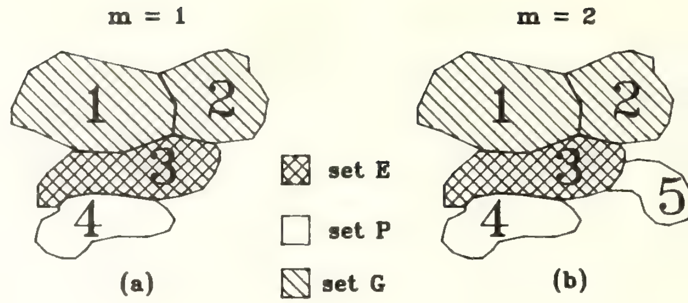


Figure 2.--Type 2 patterns comprised of a triplet and m pairs. Triplet 1-2-3 and pair 3-4 make up (a). Triplet 1-2-3 and pairs 3-4 and 3-5 make up (b).

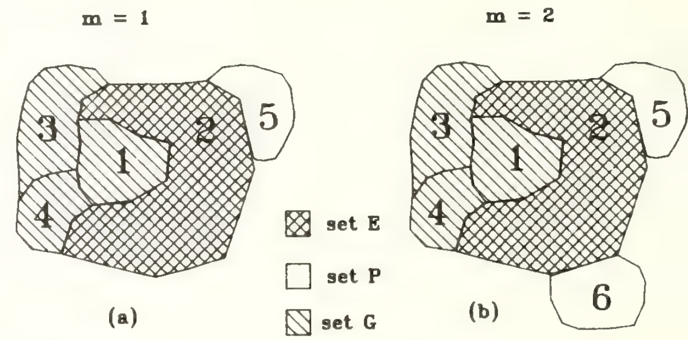


Figure 3.--Type 2 patterns comprised of a quadruplet and m pairs. Quadruplet 1-2-3-4 and pair 5-2 are shown in (a). Quadruplet 1-2-3-4 and pairs 2-5 and 2-6 are shown in (b).

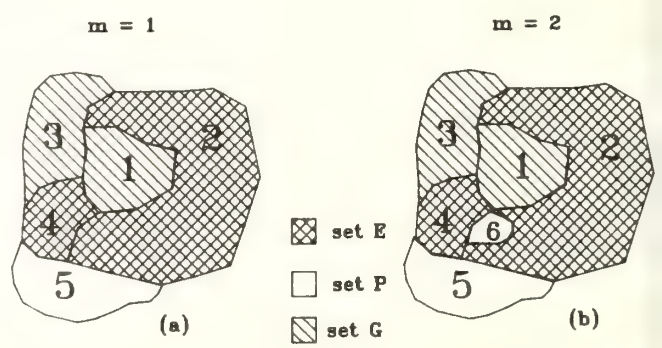


Figure 4.--Type 2 patterns comprised of a quadruplet and m triplets. Quadruplet 1-2-3-4 is shown with triplet 2-4-5 in (a) and with triplets 2-4-5 and 2-4-6 in (b).

Consider an example. Figure 8 shows a group of units and the associated adjacency matrix. Figure 9 illustrates the steps for identifying triplets and quadruplets in this matrix. The search begins with the first marked intersection (D,A), which means units D and A are adjacent. If both units D and A are adjacent to a third unit, they are part of a triplet and there will exist some row that contains marked intersections in columns A and D. Figure 9(a) shows that row C meets this condition. Therefore,

units D, A and C form a triplet. If units D, A and C are members of a quadruplet then another row will exist that contains marked intersections in columns A, D and C. Figure 9(b) shows that row B meets this condition. Therefore, units D, A, C and B form a quadruplet.

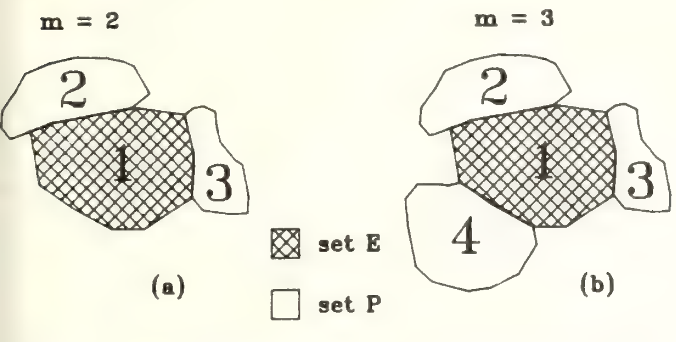
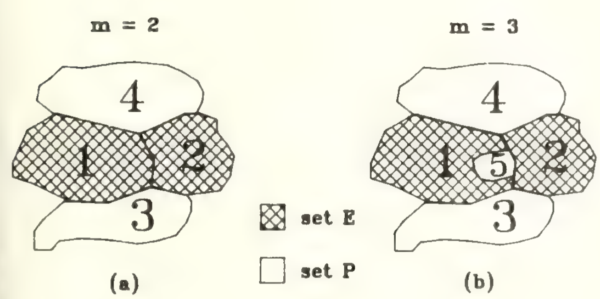
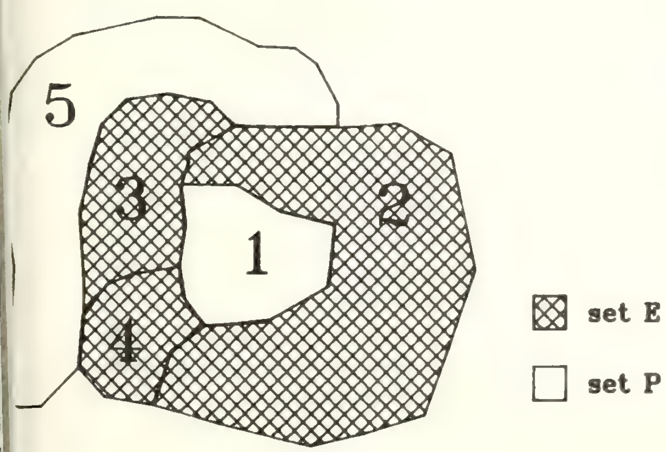


Figure 5.--Type 2 patterns comprised of m pairs. Pairs 1-2 and 2-3 are shown in (a). Pairs 1-2, 1-3 and 1-4 are shown in (b).



igure 6.--Type 2 patterns comprised of m triplets. Triplets 1-2-3 and 1-2-4 make up (a) and triplets 1-2-3, 1-2-4 and 1-2-5 make up (b).



gure 7.--A Type 2 pattern comprised of two quadruplets. Quadruplets 1-2-3-4 and 2-3-4-5 are shown.

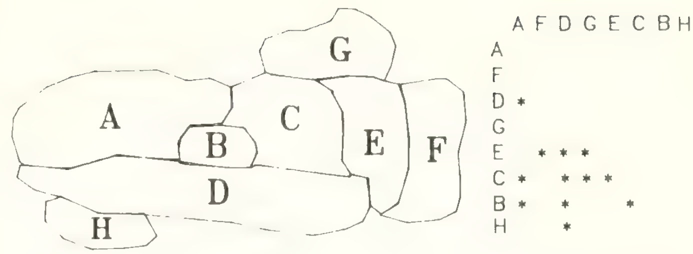


Figure 8.--A group of adjacent units and the lower half of their adjacency matrix.

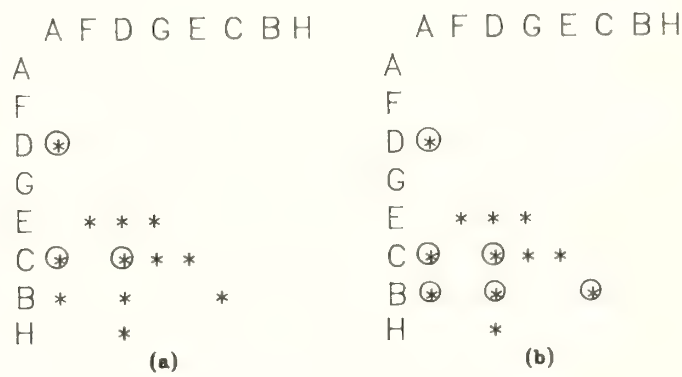


Figure 9.--The adjacency matrix for the areas shown in figure 8. The identification of triplet A-C-D is shown in (a). The identification of quadruplet A-C-D-B is shown in (b).

The entire adjacency matrix is searched according to the following procedures and rules:

1. Each marked intersection is checked starting in the upper left part of the matrix and moving down each column.
2. At each marked intersection, the section of the matrix below and to the right of it is examined for the conditions that identify a quadruplet or triplet as described above. Quadruplets are identified before triplets.
3. If a quadruplet or triplet is found the marked intersections that make up the pattern are circled as in figure 9.
4. When a quadruplet or triplet is identified it is recorded as a type 1 pattern if the following conditions are met:
   a. For a quadruplet, at least two of the marked intersections in the quadruplet must not be circled.

b. For a triplet, at least one of the marked intersections in the triplet must not be circled.

5. Any marked intersections that cannot be included in a quadruplet or triplet are recorded as Type 1 pairs.

The left half of figure 10 illustrates the results of applying this procedure to the units in figure 8.

Combining Type 1 Constraints into Type 2 Constraints

The next objective is to combine the Type 1 constraints into the smallest number of Type 2 constraints that satisfy the adjacency conditions for each unit. To represent all of the adjacency relationships, each of the Type 1 constraints created in the first step must be represented in the final set of constraints either by itself or imbedded in a Type 2 constraint. To do this, all possible Type 2 constraints are identified, then a subset of these is chosen such that all of the Type 1 constraints that were combined into Type 2 constraints are present in the subset.

Table 1 summarizes the process of identifying all possible Type 2 constraints. First, each Type 1 is listed and labeled as in the first two columns of table 1. For each Type 1, all possible combinations with other Type 1's below it that meet the conditions of a Type 2 constraint are recorded as in the third column of table 1 (combinations are listed as a set of Type 1 labels). Finally, the total number of Type 2 constraints of which each Type 1 is a member (referred to as the Type 2 frequency) is recorded as in the fourth column of table 1. The right half of figure 10 illustrates the results of the process just described.

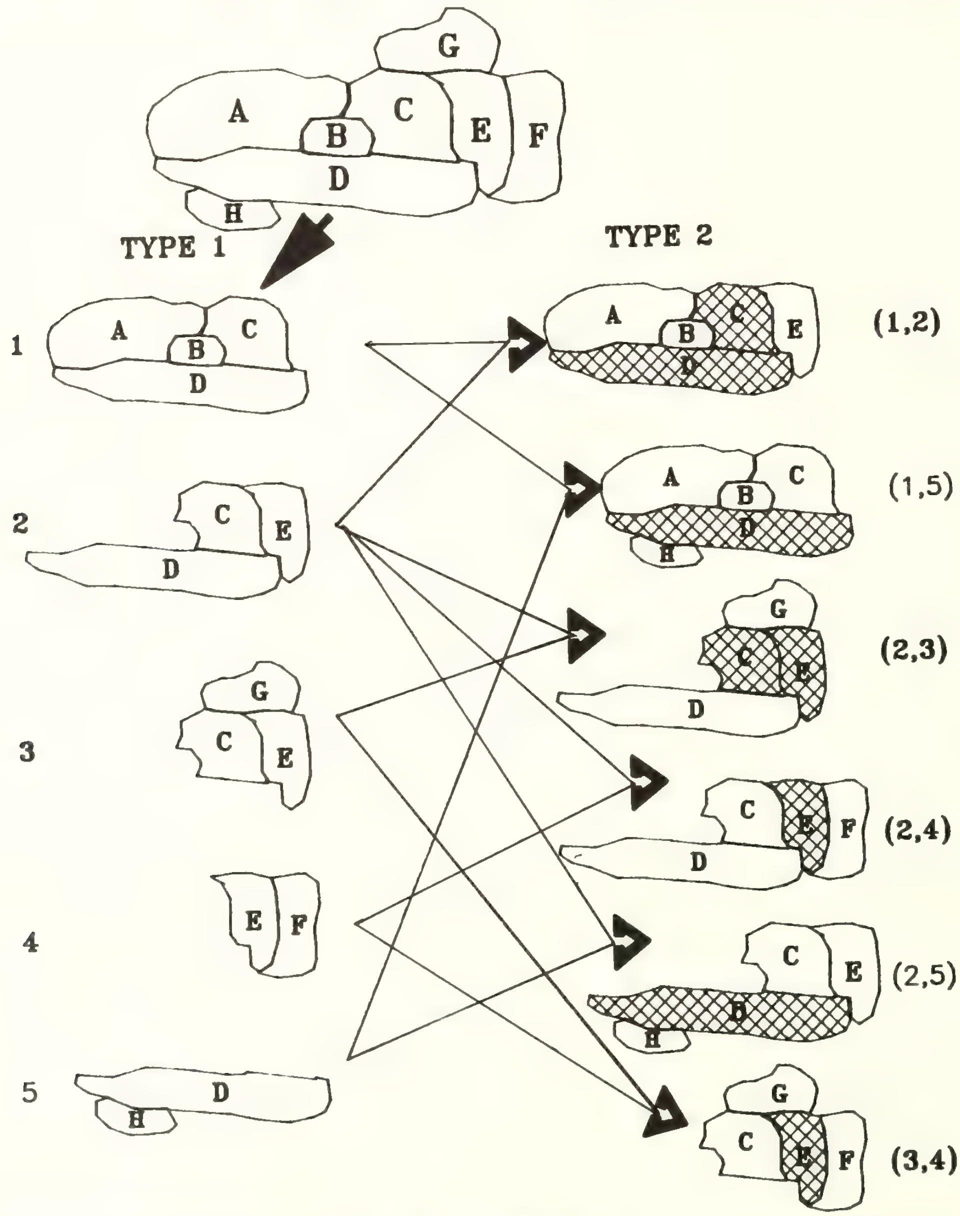


Figure 10.--A group of units is first broken down into Type 1 patterns. These patterns are then combined to form Type 2 patterns.

Table 1.--Type 1 and possible type 2 patterns for the units shown in figure 8.

Type 1 label	members	Possible Type 2 patterns	Type 2 frequency
1	A-B-C-D	(1,2),(1,5)	2
2	C-D-E	(1,2),(2,3),(2,4),(2,5)	4
3	C-E-G	(2,3),(3,4)	2
4	E-F	(2,4),(3,4)	2
5	D-H	(1,5),(2,5)	2

Table 2.-- Steps taken to choose a final set of adjacency constraints for the units shown in figure 8. The Type 1 and Type 2 patterns are defined in table 1.

Type 1 pattern	Type 2s to choose from	Choice	Decision rule
1	(1,2),(1,5)	(1,5)	Rule 4b; lower combined Type 2 frequency
3	(2,3),(3,4)	(3,4)	Rule 4b; lower combined Type 2 frequency
4	(2,4),(3,4)	--	Rule 1; skip because already included in (3,4)
5	(1,5),(2,5)	--	Rule 1; skip because already included in (1,5)
2	(1,2),(2,3), (2,4), (2,5)	(2)	Rule 4c; '2' is the only remaining Type 1 member

Table 2 summarizes the process of choosing which Type 2 constraints will be present in the final constraint set. First, the Type 1 constraints are listed by ascending order of their Type 2 frequency as in the first column of table 2. For each Type 1, the Type 2s of which it is a member is listed beside it (the second column of table 2) and one is chosen for the final constraint set according to the following rules:

1. If the Type 1 constraint has been included in a Type 2 constraint chosen previously then go on to the next Type 1.

2. If the Type 1 constraint is present in no Type 2 constraints then it is included "as is" in the final constraint set.

3. If the Type 1 constraint is present in only one Type 2 constraint and there is more than one remaining Type 1 in that set then that Type 2 constraint is chosen for the final constraint set. If there is only one remaining Type 1 then that Type 1 is included "as is" in the final constraint set.

4. If the Type 1 constraint is present in more than one Type 2 constraint, the choice follows this hierarchy:

    a. The Type 2 constraint containing the most Type 1 constraints not already included in a chosen Type 2 is chosen first.

    b. If two or more Type 2 constraints contain equal numbers of remaining Type 1 constraints, rank them according to the combined Type 2 frequency of their individual Type 1 members. The Type 2 with the lowest combined frequency is chosen first.

    c. If all the Type 2s contain only one remaining Type 1 then that Type 1 is included "as is" in the final constraint set.

Please refer to table 2 as we illustrate this procedure for the units in figure 10. Pattern '1' is included in two Type 2s ('(1,2)' and' (1,5)'). The Type 2 frequency for '(1,2)' is 6 while the Type 2 frequency for '(1,5)' is 4. Therefore, '(1,5)' is chosen. Considering pattern '3' next, there are two Type 2 patterns to choose from ('(2,3)' and '(3,4)'). Pattern '(3,4)' is chosen because its combined Type 2 frequency is lower than that of '(2,3)' (4 vs. 6). Type 1s '4' and '5' are skipped because they are included in Type 2s already chosen. Finally, considering pattern '2' we see that all the Type 1s with which it is paired have already been included in previous choices. Therefore, '2' is included "as is" in the final constraint set. For this example, the final constraint set would be reduced to only three equations as follows:

Combine	(1):	A +	B+	C +	D					≤ 1
and	(5):				D+				H	≤ 1
to get		2(A) +	2(B)+	2(C)+	3(D)+				H	≤ 3
Combine	(3):			C +		E +		G		≤ 1
and	(4):					E +	F			≤ 1
to get				2(C)+		3(E)+	F+	2(G)		≤ 3
Use	(2) as is:			C +	D+	E				≤ 1

To represent the adjacency relationships for these units with pairwise constraints would require 11 constraints.

Representing Multiple Projects and Periods

Thus far, we have considered units with only one potential project occurring in one time period. However, many operational models have alternative management and timing choices. In some cases, more than one period must elapse between activities on adjacent units. For these cases, Type 1 and Type 2 formulations are extended.

For models with multiple periods and management alternatives each management activity is represented by the variable X_{ilt} which takes on the value of 1 if alternative activity l is chosen for unit i during time period t and takes on the value of 0 if not chosen.

Adjacency constraints for models with these variables are written by reducing the variables to a simple form as in equation [1] (one time period and one project), applying the combining algorithm and finally extending the Type 1 and Type 2 inequalities of the final constraint set to include multiple periods and projects. The general form of the extended inequalities is as follows:

Type 1: $Y_a \leq 1$ [9]

Type 2: $(2r-1)(Y_e) + (Y_p) + (r)(Y_g) \leq (2r-1)$ [10]

Where

$$Y_a = \sum_{i \varepsilon A} \sum_{l=1}^{L} \sum_{t=q}^{q+n-1} X_{ilt}$$

$$Y_e = \sum_{i \varepsilon E} \sum_{l=1}^{L} \sum_{t=q}^{q+n-1} X_{ilt}$$

$$Y_p = \sum_{i \varepsilon P} \sum_{l=1}^{L} \sum_{t=q}^{q+n-1} X_{ilt}$$

$$Y_g = \sum_{i \varepsilon G} \sum_{l=1}^{L} \sum_{t=q}^{q+n-1} X_{ilt}$$

L = the number of mutually exclusive management choices for unit i

n = the number of periods that must pass between activities on adjacent units (n = 1 means activities cannot occur on adjacent units in the same period, n = 2 means they cannot occur within two consecutive periods and so on)

q = the beginning time period for the constraint

and all other notation is as previously defined.

To illustrate we will consider the units in figure 8. We have shown how the adjacency relationships for these units can be represented with two Type 2 and one Type 1 inequalities. For a case with two management alternatives and two time periods with n = 1, the inequalities for the Type 1 pattern comprised of units C, D and E would be:

$$t=1: \quad X_{C11} + X_{C21} + X_{D11} + X_{D21} + X_{E11} + X_{E21} \leq 1$$

$$t=2: \quad X_{C12} + X_{C22} + X_{D12} + X_{D22} + X_{E12} + X_{E22} \leq 1$$

The Type 2 pattern comprised of units G, C, E and F can be extended as follows:

$$\begin{aligned} Y_e = \quad & t=1: \quad X_{E11} + X_{E21} \\ & t=2: \quad X_{E12} + X_{E22} \\ Y_p = \quad & t=1: \quad X_{F11} + X_{F21} \\ & t=2: \quad X_{F12} + X_{F22} \\ Y_g = \quad & t=1: \quad X_{G11} + X_{G21} + X_{C11} + X_{C21} \\ & t=2: \quad X_{G12} + X_{G22} + X_{C12} + X_{C22} \end{aligned}$$

Therefore by substitution into equation [10] we get:

$$\begin{aligned} t=1: \quad & 3(X_{E11}) + 3(X_{E21}) + (X_{F11}) + (X_{F21}) \\ & + 2(X_{G11}) + 2(X_{G21}) + 2(X_{C11}) + 2(X_{C21}) \leq 3 \end{aligned}$$

$$\begin{aligned} t=2: \quad & 3(X_{E12}) + 3(X_{E22}) + (X_{F12}) + (X_{F22}) \\ & + 2(X_{G12}) + 2(X_{G22}) + 2(X_{C12}) + 2(X_{C22}) \leq 3 \end{aligned}$$

Test Cases

The algorithm was tested with data for sub-units of planning areas on three National Forests (NF): the Twin Rocks area of the Lolo NF, the Bonetti compartment of the Eldorado NF and the Big Springs area of the Kaibab NF. Two methods were used to determine the final constraint set. In addition to the algorithm described above, an integer programming model was used to choose the final set of Type 2 inequalities from the "all possible" set of Type 2 inequalities.

In this model, the number of Type 2 constraints was minimized, subject to the condition that each of the Type 1 patterns is imbedded in the final set of Type 2 constraints. This integer programming method provides a baseline for measuring the goodness of the last step of the combining algorithm described above. The results of the comparison, presented in table 3, show little difference between the algorithm and the method using integer programming.

These test cases, together with many smaller hypothetical problems tested by the authors, indicate some general patterns in the required number of Type 1 and Type 2 constraints. Test results show that if the majority of the units in an area have between 3 and 5 adjacent units then the number of adjacency conditions is about twice the number of units.

For this type of area, the number of Type 1 patterns is generally half the number of adjacency conditions. These Type 1 patterns can usually be combined into Type 2 patterns to reduce the number by half again. Estimates of the total number of constraints required can then be made based on the number of time periods in the model, T, and the length of time that must pass between mutually exclusive management activities, n. If S is the total number of Type 1 and Type 2 patterns after combining, the total number of adjacency constraints required to represent the adjacency relationships is S x (T-n+1).

Table 3.--Adjacency relationships on three national forest test areas and the results of applying the adjacency constraint reduction algorithm.

	Twin Rocks	Bonetti	Big Springs
Management units	28	41	56
Adjacency conditions (maximum type 1 pairs)	53	88	108
Type 1 patterns after Step I	30	46	60
Type 2 patterns after Step II			
integer programming method	15	22	28
algorithm	15	23	30

Conclusions

This paper has presented some alternative formulations for spatial relationships used in linear programming models for analyzing forest management alternatives. The underlying objective of the formulations is to reduce the number of constraints necessary to formulate adjacency constraints. In some instances, the savings are large. For the three areas studied up to a four fold decrease in the number of constraints was achieved over what would be required if the constraints were written pairwise.

Mathematical programming models constructed for operational forest management planning, by their nature, contain a large number of constraints relative to strategic planning models. The reduction in the number of constraints required to formulate the adjacency relationships, as discussed in this paper, is expected to have some combination of the following payoffs.

First, the cost of solving a mathematical programming problem is relatively sensitive to the number of constraints in the model. Reducing the number of constraints can be expected to reduce the cost of solving these models. Second, the number of constraints is usually the most limiting dimension on size for models of this type. Space saved by the formulations discussed in this paper can be used for additional constraints that model other spatial aspects of a problem or for additional decision variables that require additional constraints.

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Accounting for Stochastic Variation in Linear Programming Technical Coefficients

James B. Pickens and John G. Hof[1]

Abstract.--Two recent studies by the authors (and others) dealing with stochastic production coefficients in land allocation linear programs are discussed. One major conclusion, which was reached independently in both studies, is that selection of truly feasible solutions are unlikely if technical coefficients are random.

During recent years, operations research methods have been used increasingly in forest resource planning. Although other operations research techniques are used, linear programming (LP) is by far the most commonly employed method. LP applications are typically based on an assumption that the required data are known with certainty. This assumption is usually not tenable in forest resource planning problems. Nearly all of the required data are subject to sampling or measurement errors and/or measure intrinsically random phenomena.

A traditional approach for evaluating the effects of this unsatisfied assumption is to parametrically vary some of the data values. This approach is most often used for evaluating coefficients in the objective function or right-hand-side (RHS) values. Parametric analysis is useful to assess the impact of stochastic data if only a small portion of the extremely large number of data entries in a large LP are to be perturbed. However, this approach is not reasonable in a situation where production or cost information is suspect in large scale problems, i.e., in the case of a stochastic constraint matrix (A matrix). If parametric analysis were attempted on the constraint matrix for a realistic land allocation problem, then an impossibly large number of options would need to be evaluated and a meaningful method of solution comparison would have to be developed. This does not seem to be a viable approach for large-scale problems.

A related method of testing sensitivity to stochastic entries is chance constrained LP (Charnes and Cooper 1963). This method was applied to forage production by Hunter et al. (1976). Since this method deals with only systematic variation of production requirements or input levels (i.e., RHS's), it is not appropriate for dealing with stochastic production coefficients.

[1] *The authors are Assistant Professor, School of Forestry and Wood Products, Michigan Technological University, and Principal Economist, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.*

The purpose of this paper is to assimilate two recent works by the authors and others (Hof et al. in press, Pickens and Dress in press) concerning the impact of stochastic production coefficients in renewable resource linear programs. The research conducted by Hof et al. is directed toward the problem of optimization and the "fallacy of averages" (Wagner 1975) when the means of the stochastic production coefficients are known, while the research by Pickens and Dress describes solution characteristics that are to be expected when production estimates contain a random component in land allocation problems. A brief description of the approaches and results of the two studies follows.

The Hof, Robinson, and Betters Study

Theory

As stated above, this research focuses on the case where production (yield) coefficients are random, but with known means. Two related textbook (Wagner 1975) theorems are utilized:

(I) FALLACY OF AVERAGES. Given an arbitrary nonlinear function $f(x_1,..., x_n)$ of random variables $x_1,..., x_n$, it is usually *erroneous* to assume

$$E[f(x_1,..., x_n)] = f(E[x_1],..., E[x_n]).$$

A linear case of particular interest is if we wish to:

$$\text{maximize} \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij}x_j \gtreqless b_i \quad \text{for } i = 1, 2, \ldots, m$$

$$x_j \geq 0 \quad \text{for } j = 1, 2, \ldots, n, \text{ then}$$

(II) LINEAR CERTAINTY-EQUIVALENCE THEOREM. Assume that all the a_{ij} and b_i are known exactly, but the c_j are random variables independent of all x_j. If the levels of x_j, for j = 1,..., n, must be set prior to knowing the exact values of c_j, then a solution to:

$$\text{maximize } E\left[\sum_{j=1}^{n} c_j x_j\right]$$

subject to the constraints, is given by levels for x_j that

$$\text{maximize } \sum_{j=1}^{n} E[c_j]x_j$$

subject to the constraints.

Renewable resource linear programs are typically constrained by land area and/or resource yield constraints. This paper distinguishes two cases: one where only land area constraints are included, and a second where both land area and yield constraints are included. In the former case, it is shown that production coefficients actually enter the problem as objective function coefficients. Thus, Theorem II indicates that the expected value of the objective function (call it π) can be maximized simply by using the expected values of the production coefficients and solving with ordinary LP. It is also shown that, in this former case, the maximum expected value of π is not equivalent to the expected value of maximum π. This distinction is also important in the latter case. And, it is noted that the expected value of maximum π is typically not associated with any one particular solution vector.

In the latter case, the expected value of the objective function is still equivalent to the objective function based on expected values of coefficients--there is no fallacy of averages in the objective function values. In this case, however, randomness in the A-matrix coefficients persists, so the question of feasibility is difficult to address. Any given solution would only have some (generally unknown) probability of being feasible. Attempting to assure feasibility with 100% certainty would generally lead to extreme (plus or minus infinity) solutions, depending on the distributions of the A_{ij}.[2] Thus, maximum $E(\pi)$ is generally *indeterminate* with yield constraints, in the sense that it is not calculable. Conversely, postulating that the E(maximum π) is desired makes the problem determinate, in the sense that E(maximum π) is calculable but feasibility is uncertain in both circumstances.

[2]Another approach would be a type of "chance-constrained" formulation. Unfortunately, in contrast to the chance-constrained formulations with random right-hand-sides, this formulation has no apparent solution procedure, even with a simulation approach. Also, this formulation may or may not be consistent with a decision maker's desired solution.

The paper concludes that a risk-neutral formulation of the area and yield constrained problem is not clearly available. The only approach to the area and yield constrained problem that is solvable and has a determinate solution is to find E(maximum π). Common practice has been to treat the A_{ij} as deterministic. If this assumption is untenable, but we assume that the production coefficients utilized are expected values, then common practice is equivalent to this approach, except for the fallacy of averages defined in theorem (I). In order to investigate the implications of current common practice, a null hypothesis was adopted that these two approaches are empirically identical. This null hypothesis was tested in a test case with both area and yield constraints.

Case Study

The case study is designed so as to emulate the actual process typically used to develop a timber harvest scheduling LP model, with the random variation in yields based on empirical observations, rather than an assumed distribution. Field data from a single 10-point timber inventory plot sample (USDA Forest Service 1976) was obtained for a stand of mixed conifers in western Montana. A bootstrap technique (Diaconis and Efron 1983) was used to generate a "population" and 20 random samples. The procedure was to draw 62 trees from the original 62 observations, one at a time, with replacement. This was repeated 20 times, yielding the bootstrap equivalent of 20 samples (each with 62 observations) of the population. The bootstrap approach implicitly assumes that the original sample captures the variability of the population. In typical timber inventories, the population characteristics are not known.

Twenty different (small) linear programs were built, one for each of the twenty different sets of yield predictions (but identical otherwise). The problem was to schedule harvesting options over eight 10-year time periods and two land areas so as to maximize discounted net revenue, subject to management constraints. The mean of the 20 maximized objective functions was interpreted as an estimate of the expected value of the maximum objective function (π). Another linear program was also solved utilizing the mean yield coefficients. This solution represented current common practice.

The estimate of the expected value of the maximum objective function value was less than one percent less than the optimal objective function value using mean yield coefficients. The fallacy of averages is indicated to be quite small in this simple case example. The stochastic variation in the 20 different bootstrap samples resulted in substantially different acreage allocations; however, the average of the 20 different allocations (an estimate of the expected value of the optimal allocation), was quite similar to the allocation based on mean coefficients. The question of feasibility remains. The solution (allocation) based on the mean yield coefficients was imposed on the 20 different bootstrap sample coefficient sets, and infeasibilities resulted in *all 20* models. This raises questions as to the

appropriateness of the expected value of the maximum objective function as a postulated decision criterion.

The study drew the following conclusions: If only area constraints are included, current practice is equivalent to maximizing the expected value of the objective function (π), because the yield coefficients actually enter the problem as objective function coefficients. This is not equivalent to the expected value of maximum π. If both area and yield constraints are included, then constraint coefficients are unavoidably random and the maximum expected value of π is indeterminate because of uncertain feasibility. If an "acceptable probability of feasibility" can be specified, the maximum expected value of π would be, in principle, determinate, but no solution procedure for this formulation appears to be available at this time. The expected value of maximum π is determinate with both area and yield constraints, and can be estimated with simulation techniques as in the case study. However, no single solution is associated with this value, and feasibility is still uncertain (with unknown probability). The only distinction between this approach and current practice is the fallacy of averages caused by the nonlinearity between the expected value of maximum π and the technical coefficients. The case study indicates that this fallacy of averages may not be large. If this empirical finding is representative, then current practice may generate approximations to the expected value of maximum objective function values and the expected value of the optimal solution (acreage allocation). However, the case study also implies that current practice may lead to solutions that have low probabilities of being feasible.

The Pickens and Dress Study

As stated above, the central question of this research was: What solution characteristics are to be expected when production estimates with a random component are used in land allocation problems?

To address this problem a test land allocation model was developed and a simulation approach was employed. The model used data originally developed for the 1980 Assessment required by the Renewable Resource Planning Act. The data generation instructions are documented in the Book of Procedures (USDA Forest Service 1977). The test model does not include dynamic allocation over time, but is quite large with 292 analysis areas and about 10 prescriptions per analysis area. The large size was required to allow development of statistical arguments about the distribution of the solution parameters discussed below. The large model size is one major point of divergence between the methods used in the two studies discussed in this paper.

Thirty simulations for each of several model structures were run. The model structures can be classified into two distinct groups: unconstrained models (except for land area constraints) which employ several different error structures (probability density function and degree of variability) for perturbing production estimates; and constrained models using only normally distributed random deviates with a coefficient of variation of 0.1. All simulations maximized present value as the objective function.

For the unconstrained models, simulations using three error distributions, the normal, Cauchy, and double exponential, were conducted. However, only the simulations with normal random deviates will be discussed here. Separate simulations were run for three different coefficients of variation, 0.1, 0.3, and 0.5.

Two random variables were observed for each simulation. The first random variable observed was the value of the objective function when the perturbed production estimates were employed and the linear program was solved. This is referred to as the perturbed objective function value. The other random variable observed is the value of the objective function when the original (and assumed correct) production estimates are used to evaluate the objective function using the optimal decision variable activities from the perturbed problem. This random variable is called the true objective function value. The relationship of these random variables is important. The perturbed objective function would be all that is observed in an actual application with stochastic production coefficients. The true objective function represents the expected return when the optimal solution of the perturbed problem is actually implemented.

In order to evaluate the simulation results, the original problem, with no random errors applied, was solved. This solution is referred to as the base solution, and represents the result if perfect information were available.

Two additional random variables can be calculated using the base solution objective function value and the two previously defined random variables. The bias is calculated as the perturbed objective function value minus the true objective function value, and represents the amount that the perturbed objective function would deviate from the true response of the system. The loss is calculated as the base solution objective function value minus the true objective function value, and represents the potential gain to be expected if perfect information were available for planning.

The Effects of Stochastic Production Coefficients on Unconstrained Model Solutions

The following conclusions were drawn concerning the impact of stochastic production coefficients in the unconstrained case:

1. The perturbed objective function produces biased estimates of the actual response of the system, the true objective function value. The bias is positive (optimistic).
2. The distribution of the resulting true objective function, the perturbed objective function, and the bias were tested for divergence from normality.

Both the bias and the perturbed objective function appeared to be normally distributed, while the true objective function was significantly different from normal. These distributional results would be expected to vary significantly if small land allocation problems were used for similar testing because the rational for normally distributed results requires large sample sizes.

3. The perturbed objective function was distributed with a mean higher than the base solution value.

4. The true objective function will always be less than or equal to the base solution. This absolute upper limit is the reason that the true objective function was not normally distributed.

5. As would be expected, loss and bias both increased with coefficient of variation.

The Effects of Stochastic Production Coefficients on Constrained Models

Two different types of constraints were considered to evaluate the impact of stochastic production coefficients on constrained models. These two constraint types are:

1. Constraints which cannot be rendered infeasible by the stochastic production coefficients. An example of this type of constraint is a budget constraint when management costs do not vary with production level.

2. Constraints which involve the stochastic production coefficients, and therefore can be rendered infeasible in the original problem when the optimal solution of the perturbed problem is imposed.

The simulations for constrained models were restricted to normal errors with a 0.1 coefficient of variation. Only one constraint was applied to evaluate the impact of each type of constraint.

The Case Where Continued Feasibility Is Assured

To simulate the case where feasibility could not be affected, a budget constraint limiting expenditures to 80 percent of the base budget was applied. The simulation results were similar to those observed in the unconstrained simulations discussed above. Conclusions one through four listed above still held in this case.

One additional type of information is available for comparison with constrained problems--the dual activity for the global constraint. Interestingly, the dual activities observed in the simulations were significantly different than the dual activity observed for the base cost constrained solution, which used the original data without random perturbations to the production coefficients. This indicates that, when stochastic production coefficients are used, the dual activities observed are biased estimates of the values that would be observed if the correct production information were used. In this case the constraint appears more costly than it would really be. This can be explained by recalling that the optimization selectively chooses options with large positive errors in estimated production. Since the options being selected are optimistic estimates, the budget constraint implies a greater reduction in production than would really occur.

The Case Where Feasibility Is No Longer Assured When Global Constraints Are Applied

For the case where feasibility could be affected, a timber harvest constraint set at 1.2 times the base timber harvest was imposed. Conclusions one and three from above are still true. Conclusion two and four must be modified somewhat. From conclusion two, the bias and perturbed objective functions still appear to be normally distributed. However, the true objective function, which previously did not appear to be normally distributed, appears to be normally distributed in this simulation. This can be explained by the fact that conclusion four, that the true objective function value is bounded above by the base objective function value, is no longer true. Because feasibility is not assured, the optimal solution to the perturbed problem need not be feasible when imposed on the original, and assumed correct, problem.

The dual activity of the timber-constrained simulations were, as in the cost-constrained case, biased estimates of the base dual activity. The base dual activity was -0.476798, while the mean of the simulations was -0.327695. These values were significantly different at $\alpha = .01$ ($t = 4.398$). In this case the dual activity causes the constraint to appear less costly than it really is. The direction of the bias can again be explained by the tendency of the optimization to select options with optimistic production estimates.

The implications for solution feasibility of using stochastic production coefficients in constraints which can be rendered infeasible because of the errors in estimation are quite disturbing. Of the 30 simulation solutions, and with only one output constraint, 27 of the optimal solutions actually were not feasible. Underachievement of the timber goal was as high as 11 percent. This would imply that, in an average forest planning problem where time dynamics and many output constraints are included, there is nearly no chance that the resulting solution is truly feasible.

The tendency to select infeasible solutions can be explained by two factors. First, recall that, in the unconstrained model, positive errors in estimation of output quantities tended to be selected. This fact led to the conclusion that the results of LP models are optimistically biased when stochastic production coefficients are used. Second, because the model is required to

produce a specific amount of the output that is constrained, an added tendency to choose optimistic estimates is included.

Conclusions

In this paper two very different approaches to evaluate the impact of stochastic production coefficients in land allocation linear programs have been reviewed. The two approaches address very different research questions and employ methods totally dissimilar, but both reach the same conclusion; land allocation linear programs with stochastic production estimates are very unlikely to find feasible solutions as they are typically solved.

Another common conclusion from both papers is, unfortunately, that an approach that ameliorates this problem is not currently available. In fact, the two papers point out that it is not clear what the correct formulation for optimization with random production coefficients is in the first place. A good deal of further research is needed in this area, and in the meantime, caution is indicated when using LP in uncertain environments.

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Choice of Multicriterion Decision Making Model for Forest Watershed Resources Management

Aregai Tecle, Martin M. Fogel, and Lucien Duckstein[1]

Abstract.--An algorithm for selecting a multicriterion decision making (MCDM) technique for forest watershed resources management is modeled as a multicriterion problem. The procedure involves evaluation of feasible alternative MCDM techniques with respect to different sets of choice criteria. A particular technique is used to analyze the problem leading to a preference ranking of the alternative MCDM techniques.

The purpose of this paper is to present a procedure by which the most suitable MCDM technique can be selected for application to a multicriterion forest watershed resources management problem. Of explicit concern is the matching of a given multicriterion watershed resources management problem with an appropriate technique.

Considering the large number of techniques available, an applied analyst can get confused in determining which technique to choose when confronted with a real problem. Such ambiguity can cause inappropriate selection of a MCDM technique resulting in a misleading solution and wrong conclusions. For example, Cohon and Marks (1975), in their classification of MCDM techniques that can be used to solve water resources problems, stated that the ELECTRE method was not applicable to these problems. Krysztofowicz et al. (1977), however, stated the opposite by pointing out that ELECTRE was successfully applied to water resources problems and that its use in this area should be continued. The latter was further proven to be true in a subsequent study by Gershon et al. (1982). Given such apparent contradictions, it is not surprising to see a mismatch in practice between a real world problem and the MCDM technique applied to solve that particular problem.

There are four possible consequences of this kind of mismatch. First, as stated above, the solution resulting from poorly matched problem-MCDM technique situation will be misleading or unsatisfactum. Second, useful techniques may be judged inappropriately like that of ELECTRE in Cohon and Marks (1977), due to the poor results obtained, because they are applied incorrectly. Third, the mismatch subsequently results in wrong decisions incurring losses in valuable time, energy, and money. Finally, it may discourage potential users from applying MCDM techniques to real world problems. To avoid these kinds of problems, a procedure for selecting the "best" solution technique for a particular problem is presented in this paper.

The paradigm for selecting an appropriate MCDM technique for evaluating a multicriterion forest watershed resources management problem can be briefly described in terms of the following steps:

1. Defining the desired objectives or purposes that the MCDM techniques are to fulfill.
2. Selecting evaluation criteria that relate technique capabilities to objectives.
3. Listing and specifying MCDM techniques available for attaining the desired objectives, that is, solving multicriterion watershed management problems.
4. Determining technique capabilities or the levels of performance of a technique with respect to the evaluation criteria in solving a multicriterion problem.
5. Constructing an evaluation matrix (techniques versus criteria array), the elements of which represent the capabilities of alternative techniques in terms of the selected criteria (obtained in step 4).

[1]*Research Scientist University of Arizona, School of Renewable Natural Resources, Tucson, AZ 85721, U.S.A.; Professor, University of Arizona, School of Renewable Natural Resources, Tucson, AZ 85721, U.S.A.; and Professor and Chairman, Case Western Reserve University, Department of Systems Engineering, Crawford Hall, Cleveland, OH 44106, U.S.A.*

6. Analyzing the merits of the alternative MCDM techniques with respect to a given multicriterion forest watershed resources management problem and selecting the most satisficing technique.

Steps 1 through 5 constitute the multicriterion formulation procedure, while step 6 is the implementation of the MCDM technique selection procedure. The roles of these steps in the selection process, that is the steps of the technique selection algorithm, are described in the subsequent sections.

Background

The growth and diversification of MCDM techniques in recent years have been phenomenal. In spite of this, however, the applied practitioner, for a variety of reasons, has not used the techniques extensively. This problem of MCDM techniques not being implemented is well documented in the literature as shown in Evans (1984), Romero and Rehman (1987), Shannon (1975), and Zionts (1979) among others. One reason for this problem may be the lack of guidelines to match an appropriate technique to a particular real world problem, that is, there appears to be no framework general enough to guide practitioners in various fields in choosing an appropriate MCDM technique for application to multicriterion problem of their choice.

Criteria for Selecting MCDM Techniques

The selection of a MCDM technique for solving a multicriterion problem is dependent upon a set of selection criteria. Tecle (1988) identified 49 different criteria upon which the choice of an appropriate MCDM technique for a particular problem can be based. These criteria can be categorized into four groups depending on whether they describe mainly (1) the characteristics of the decision maker (DM) and/or analyst involved, (2) the characteristics of the algorithm for solution, (3) the characteristics of the problem under consideration, or (4) the nature of the obtainable final solution.

In this paper only 24 selection criteria are used for evaluating the appropriateness of a set of MCDM techniques to solve a forest watershed resources management problem. The limiting factor for utilizing only 24 criteria is the lack of adequate information on the actual use of the rest of the criteria to evaluate the performance of the techniques in solving such problems. The role of the 24 criteria in the evaluation process will be discussed later. In the meantime, a list of feasible MCDM techniques are provided from which the best technique for forest watershed resources management is selected.

Alternative MCDM Techniques

More than 70 MCDM techniques were identified in Tecle (1988). However, it would be very difficult if not impossible for any one individual to be skilled enough to apply all of those techniques, and experience in the use of a technique is a prerequisite for evaluating a techniques with respect to a set of criteria (Duckstein et al. 1982, Gershon 1981, Gershon and Duckstein 1984). With this idea in mind, only a few MCDM techniques are considered for evaluation in this study. These are the set of alternative techniques in table 1 with which the author has some familiarity. Here, they are evaluated for their suitability to solve a multicriterion forest watershed resources management problem such as the one described in Tecle (1988).

Evaluation of MCDM Techniques

In this section, a way of evaluating the performance of the alternative MCDM techniques under consideration is provided. This evaluation is made with respect to each of the four different groups of criteria, that is, DM/analyst-related criteria, technique-related criteria, problem-related criteria, and solution-related criteria, separately. This procedure lays the basis for the development of four evaluation matrices each of which consisting of techniques versus criteria array. The array elements are the evaluation scores of all the techniques with respect to each criteria in each criterion group. The level of these scores are based on the authors experiences in applying the techniques as well as the evaluation results of previous works such as those of Cohon and Marks (1975), Duckstein et al. (1982), Gershon (1981), Gershon and Duckstein (1984), Khairullah and Zionts (1979), Ozernoy (1987), and Rietveld (1980). The arrays so formed in turn provide the information necessary to achieve the desired choice of techniques.

Table 1.--Alternative MCDM techniques considered for selection.

1.	Analytic Hierarchy Process (AHP) (Saaty 1977, 1980)
2.	Composite Programming (CTP) (Bogardi and Bordassy 1983)
3.	Compromise Programming (CP) (Zeleny 1973, 1982)
4.	Cooperative Game Theory (CGT) (Nash 1953, Szidarovszky 1984)
5.	Displaced Ideal (DISID) (Zeleny 1974, Nijkamp 1979)
6.	ELECTRE (ELEC) (Benayoun et al. 1966, Roy 1968)
7.	Evaluation and Sensitivity Analysis Program (ESAP)
8.	Goal Programming (GP) (Charnes and Cooper 1961, Ignizio 1976)
9.	Multiattribute Utility Theory (MAUT) (Keeney and Raiffa 1976)
10.	Multicriterion Q-Analysis (MCQA) (Duckstein and Kempf 1979)
11.	Probabilistic Tradeoff Development Method (PROTR)
12.	Zionts-Wallenius (Z-W) (Zionts and Wallenius 1976)
13.	Step Method (STEM) (Benayoun et al. 1971)
14.	Surrogate Worth Trade-off (SWT) (Haimes and Hall 1974)
15.	PROMETHEE Method (PRM) (Brans and Vincke 1985)

After constructing the evaluation matrices consisting of alternative MCDM techniques versus criteria array, the DM's preference structure over the set of criteria in each matrix is determined to complete the problem formulation stage. Every criterion in any one of the four categories is assigned a weight relative to its importance in that group and also reflecting its significance with respect to the problem at hand. For example, when considering the technique-related criteria, ease of coding is weighted much higher than the "number of parameters required" in a technique. Based on the author's experience, it is more difficult to understand and use a technique characterized by coding complexity than one which requires a lot of parameters to apply, all other characteristics remaining the same. This is the reason for attributing the higher weight value to ease of coding than to the number of parameters required. In this paper, the criterion weights in each group are presented as part of the evaluation matrix corresponding to each criterion group. The process of constructing the evaluation matrices is described in the following subsections.

Evaluation Using DM or Analyst-Related Criteria

The DM or analyst-related criteria are those for which the MCDM techniques are evaluated with respect to the DM's or analyst's level of knowledge and willingness to use them. For evaluating the performances of MCDM techniques with respect to these criteria, the following questions can be asked:

1. How much knowledge is required of the DM to understand and use the techniques?
2. How much desire does the DM have for interaction?
3. How much of the DM's time does the technique require?
4. How much actual knowledge does the DM need to have to use the technique?
5. What level of skill does the analyst need to have to use the technique?

The responses to these questions can be made irrespective of the characteristics of the problem under consideration, that is, no knowledge of the problem is required to evaluate the techniques using this group of criteria. Evaluation with respect to these criteria is made using a subjective scale with a value ranging from one to ten, where one represents the worst extreme case, that is, a task the particular technique does not fulfill and ten indicates the best possible performances that can be attributed to the particular technique. In this manner the evaluation matrix of table 2 is constructed.

Evaluation Using Technique-Related Criteria

The technique dependent criteria are another group of characteristics for which the MCDM techniques can be evaluated without any knowledge of the problem upon which the techniques are to be applied. The techniques can be evaluated once by the analyst with respect to these criteria and the results of that evaluation can be used in all composite evaluation schemes involving different problems (Gershon and Duckstein 1984). The technique-related criteria used in this study are:

1. CPU time required by the technique.
2. Number of parameters required in using the technique.
3. Ease of using the technique.
4. Computational burden experienced in utilizing the technique.
5. Ability of the technique to get efficient points.
6. Ease of coding.

The evaluation of the MCDM techniques with respect to these criteria is made using a subjective scale similar to that utilized in the DM/analyst-related criteria case. Due to the subjective nature of such ratings, it is important for each analyst making use of MCDM techniques to construct his/her own table like that shown in table 3. This method was followed by Gershon (1981) and Gershon and Duckstein (1984) during the development of their model choice algorithm. Having used one MCDM technique many times, an analyst is certain to consider it "easy to use" due to his familiarity with it (Gershon 1981).

Table 2.--Evaluation matrix of techniques versus DM or analyst-related criteria.

		Alternative techniques														
Criteria	Weight	CP	CGT	CTP	GP	STEM	MAUT	ESAP	MCQA	ELEC	AHP	Z-W	PROTR	SWT	DISID	PRM
DM's level of knowledge	4	4	3	6	5	6	3	4	7	9	5	9	2	4	4	9
DM's desire to interface	3	9	9	10	8	5	7	8	9	8	6	3	2	5	5	8
Time avail. of DM	3	10	10	8	8	5	3	2	9	9	7	7	5	6	6	8
DM's actual knowledge	2	9	7	8	10	9	6	5	10	8	7	7	4	7	9	7
Analysts skill	1	10	9	8	7	6	7	6	4	3	6	6	7	5	8	6

Table 3.--Evaluation matrix of techniques versus technique-related criteria.

		Alternative techniques														
Criteria	Weight	CP	CGT	CTP	GP	STEM	MAUT	ESAP	MCQA	ELEC	AHP	Z-W	PROTR	SWT	DISID	PRM
CPU time required	3	6	4	4	7	7	4	3	8	10	6	7	7	4	5	8
No. of param required	2	9	9	7	7	6	8	7	4	5	7	7	6	5	9	7
Ease of use	4	8	7	6	8	1	9	7	9	7	7	8	8	2	6	8
Computational burden	4	6	5	7	7	7	4	4	9	8	8	7	5	2	6	7
Ability to get eff. points	5	8	9	9	1	5	8	6	6	4	5	8	8	10	7	4
Ease of coding	4	8	9	6	7	7	8	7	9	7	7	6	3	1	8	7

Evaluation Using Problem-Related Criteria

In order to employ some of the problem-related criteria for evaluation of the techniques, it must be asked if the particular technique can be applied to perform the following tasks in a forest watershed resources management problem. The tasks considered here relate the ability of the techniques to:

1. solve problems with non-numerical data.
2. choose from among a finite number of alternatives.
3. solve nonlinear problem.
4. handle a large scale problem.
5. handle an infinite number of alternatives.
6. solve a dynamic problem.
7. handle integer or mixed integer problem.

The multicriterion forest watershed resources management problem described in Tecle (1988) is considered for evaluating the performance of the individual alternative MCDM technique with respect to these seven criteria. Since the given problem can be solved in both discrete and continuous forms and since multicriterion forest watershed resources problems can be constructed using either numerical data or mixed data as shown in Tecle (1988) and Tecle et al. (1987), all the 15 MCDM techniques in table 1 are taken as feasible alternatives to solve a forest watershed resources management problem.

Evaluation of the applicability of the techniques with respect to the problem-related criteria is made using a "yes" or "no" response to the above seven tasks. But, the responses can be provided in the form of the binary numbers 0 and 1 as shown in table 4, where 0 stands for a no-response and 1 stands for a yes-response, for computational purposes. The types of responses are based on the author's experience in applying the techniques and evaluation of works of others as stated previously.

Evaluation Using Solution-Related Criteria

The preference of one MCDM technique over another is also a function of the nature of the solution to be obtained using the techniques for the particular problem under consideration. The nature of the solution may be described by its uniqueness, reliability, and efficiency among others. Given such solution characteristics, all the feasible techniques can be assessed from the solutions obtained in their past applications to specific real-world problems or they can be applied to the particular problem under consideration and then compare the solutions obtained with each other in terms of a set of solution-related criteria. The following solution-related criteria are used to evaluate the MCDM techniques in this study:

1. Consistency of solutions obtained.
2. Robustness of results with respect to changes in the values of parameters.
3. Usefulness of the solutions to the DM.

Table 4.--Evaluation matrix of techniques versus problem-related criteria.

		Alternative techniques														
Criteria	Weight	CP	CGT	CTP	GP	STEM	MAUT	ESAP	MCQA	ELEC	AHP	Z-W	PROTR	SWT	DISID	PRM
Handle qual. data	5	1	1	1	0	0	1	1	1	1	1	0	0	0	1	1
Finite no. of altern.	4	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1
Non-linear problem	3	1	1	1	1	1	0	0	0	0	1	0	1	1	1	0
Problem size	3	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1
Infinite no. of altern.	4	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0
Dynamic problem	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Handle integer	2	1	1	1	1	0	1	1	1	1	1	0	0	0	0	1

Table 5.--Evaluation matrix of techniques versus solution-related criteria.

Criteria	Weight	Alternative techniques														
		CP	CGT	CTP	GP	STEM	MAUT	ESAP	MCQA	ELEC	AHP	Z-W	PROTR	SWT	DISID	PRM
Consistency of results	2	8	6	9	7	8	10	7	4	5	7	5	9	10	8	4
Robustness of results	2	8	6	9	7	7	8	7	8	9	6	6	7	6	9	7
Usefulness of results of DM	3	6	7	8	5	6	9	8	8	8	6	9	8	7	7	6
Confidence of results	3	7	6	8	5	5	3	3	6	5	5	7	6	5	6	6
Strength of eff. sol.	1	7	9	7	2	5	4	4	3	4	5	4	5	6	2	3
No. of sol. in each altern.	1	9	5	7	9	7	7	6	3	4	6	6	7	8	8	4

4. DM's confidence on the results obtained.
5. Strength of the efficient solution.
6. Number of solutions occurring in each iteration during the solution process.

Much as in the other criterion groups, the evaluation of the techniques with respect to this group of criteria is also made using subjective scales. The range of the scale values is similar to that in the first two cases. Unlike in the latter cases, however, knowledge of the problem and a good idea about its anticipated possible solution are required to evaluate a technique in this one. The evaluation scores of table 5 are, therefore, determined from actual applications of the techniques to multicriterion forest watershed resources management problems made at different times by such researchers as Bardossy et al. (1985), Goicoechea et al. (1976), Khalili (1986), Tecle (1987), and Tecle et al. (1987). Other helpful information for evaluation was also obtained from various studies on related resources management problems such as those pointed out at the beginning of this section.

Solving the MCDM Technique Selection Problem

The different sequential steps taken during a multicriterion lecision making process can be lumped into two complemen-ary stages: the problem formulation stage and the problem solution stage. The problem formulation stage which includes he activities described in the four parts of the above section culminates in the formation of the evaluation matrices. The problem solution stage, on the other hand, constitutes the application of a MCDM technique on the matrices to determine he desired solution. According to Wymore (1976), the problem ormulation stage is as important, if not more important, than the olution stage. This is particularly true for problems concerning arge scale systems where, at least partly, the manner in which he problem is formulated helps in determining the most suitable MCDM technique to use (Gershon and Duckstein 1984).

The objective of the technique selection algorithm is to elect the most appropriate MCDM technique for solving a orest watershed resources management problem from among the given set of feasible alternative techniques. The constructed evaluation matrices of the technique choice problem partly provide the information needed to make the choice of a technique. The other part comes with the application of a selection algorithm on these evaluation matrices.

Now, since the problem of selecting MCDM techniques is itself a multicriterion problem, the MCDM technique selection algorithm can be applied to select the technique for this purpose also. But as Gershon and Duckstein (1984) pointed out, this procedure would lead to a cyclical process. To avoid this problem, a technique must be arbitrarily chosen and applied on the MCDM choice evaluation matrices to select the most satisficing technique for the problem at hand. This choice, however, must take into account the type of the problem to be solved. In this case, for example, since the MCDM technique selection problem is defined by a discrete set of systems and must be analyzed in two levels that consist of (1) solving each evaluation matrix separately and then (2) combining the results obtained to form a new evaluation matrix from which the final compromise solution is determined, the technique choice cannot be just arbitrary. This is because the discrete formulation and the two-level solution procedure requirements of the problem limit the selection of the choice algorithm.

The algorithm which fulfills this requirement and is used for the purpose of selecting the best MCDM technique is composite programming (CTP) (Tecle 1988). This algorithm is an extension of compromise programming (Bardossy et al. 1985) and is adapted here to perform the two level trade-off analysis required in the technique choice problem. In the first level, different L_p-norms are applied to seek a compromise within each of the four criterion groups and then a different L_p-norm is applied to make a trade-off among these four groups to arrive at the final preference ranking of the alternative MCDM techniques under consideration.

Discussion of Results

The solution to the MCDM technique selection problem is obtained in terms of a L_p-distance from an ideal point. The ideal point in this case is considered to be the point consisting of the highest criterion score in each row of the evaluation matrix.

Since composite programming algorithm was used to solve the problem, the results for the two levels of analysis are presented at first. Table 6 represents the compromise solutions corresponding to the four evaluation matrices of tables 2 through 5.

It is interesting to note in table 6 that the preference ranking of the alternative techniques differ from one criterion group to the other. If the status of ELECTRE is examined, for example, it is observed to be ranked first when evaluated using the DM/analyst-related group of criteria but falls to ninth, fourth, and tenth ranks when evaluated using the problem, technique, and solution-related groups of criteria, respectively. There are at least two good reasons for this phenomenon.

One reason could be due to biases attributable to the way the subjective performance evaluation scores are obtained and the method of assigning the criterion weights and other parameters used. The performance evaluation scores were determined on the bases of the experiences of individuals in using the techniques while the criterion weights and the other parameters are meant to represent the DM's preference structure and the effect of the criterion score magnitude, respectively. Among the techniques considered, ELECTRE is one of the most widely used techniques. This is particularly true when the European experience with MCDM is taken into consideration.

The other reason is due to the fact that the different criterion groups evaluate quite different characteristics of the techniques. The ranking within each group is a function of the manner the performance of the technique in solving a particular problem is evaluated with respect to the criteria in that group. Since ELECTRE is taken to represent all four ELECTRE types, the evaluation scores used are representative of the average performance levels of all four types. Besides, there are some

Table 6.--Compromise ranking of alternatives and their respective L_p-distance.

	Criteria groups							
	DM/analyst		Technique		Problem		Solution	
Alts.	Value	rank	Value	rank	Value	rank	Value	Rank
CP	2.340	4	2.855	1	0.000	1	5.117	7
CGT	3.594	10	4.818	5	3.000	2	5.147	8
CTP	3.042	6	6.031	7	0.000	1	0.584	1
GP	2.556	5	11.413	14	7.071	8	9.831	15
STEM	3.226	8	9.580	13	7.348	9	6.287	10
MAUT	4.677	14	6.472	9	5.196	5	9.019	13
ESAP	4.564	13	7.988	12	5.196	5	9.256	14
MCQA	1.524	2	4.428	3	5.831	6	4.472	5
ELEC	1.465	1	6.582	10	5.831	6	4.375	4
AHP	3.173	7	5.401	6	5.000	4	7.295	12
Z-W	3.285	9	3.000	2	6.856	7	4.903	6
PROTR	5.718	15	6.655	11	7.937	10	2.367	2
SWT	3.929	12	13.855	15	7.937	10	5.618	9
DISID	3.758	11	4.797	4	3.606	3	2.887	3
PRM	1.938	3	6.387	8	5.831	6	6.910	11

Table 7.--Final overall ranking of alternatives for a particular inter-criterion group trade-off parameters.

Technique	Distance value	Rank
Compromise programming	3.0074	1
Composite programming	3.9427	2
Displaced ideal	4.0227	3
Cooperative game theory	4.3099	4
Multicriterion q-analysis	4.7194	5
Zionts-Wallenius method	4.8567	6
Analytic hierarchy process	5.5514	7
ELECTRE methods	5.6188	8
PROMETHEE methods	6.0370	9
Probabilistic trade-off development method	6.4037	10
Multiattribute utility theory	6.5810	11
Evaluation and sensitivity analysis program	7.2692	12
Step method	7.8649	13
Goal programming	9.3320	14
Surrogate worth trade-off method	10.1758	15

limitations to its use. It can only be applied to discrete problem that have finite numbers of alternatives (Duckstein and Bogard 1987). It is no wonder then to see ELECTRE having very lov preference ranking, tenth, when evaluated with respect to th solution-related criteria.

The discrepancies in the rankings of the other alternative with respect to the different groups of criteria can be explaine similarly. But since our interest is in the final preferenc ranking, the results of the second level of evaluation becom more important. These results are shown in table 7 where th overall preference rankings and the associated L_p-distances o the alternatives under consideration are determined.

Of the 15 techniques examined, compromise programmin (CP), composite programming (CTP), the method of the dis placed ideal, and cooperative game theory in that order are foun to be the most preferred techniques. Since all of these technique are of the distance-based type, the concept of distance may hav helped to make these techniques be easily understood an become popular. The reason for their high ranking, however, i much more than that and may be explained by looking back a the results of the first stage of evaluation in table 6.

All four techniques are highly rated with respect to th problem-related criteria as shown in the sixth and sevent columns of table 6. These techniques can handle all the task ascribed by this group of criteria except the task of directl solving problems having non-numerical data. Problems of th latter type are usually handled by a heuristic scaling procedur which consists of converting the data into numerical forr (Gershon et al. 1982, Tecle 1986, Tecle et al. 1987a).

The situation, however, is quite different when the tech niques are evaluated with respect to the other criterion group With respect to the DM/analyst criterion group, compromis programming and composite programming are ranked fourt and sixth while cooperative game theory (CGT) and the metho of the displaced ideal fall to the tenth and eleventh rank

respectively. The reason for this is that CGT and the method of the displaced ideal are rated low with respect to some of the criteria in this group. Both techniques, for example, require the DM to have some knowledge of utility theory, the concepts of the ideal point, in the displaced ideal, and status quo point in the case of CGT and some axioms to understand and use the techniques (Szidarovszky et al. 1978, 1984; Zeleny 1982).

For this reason their evaluations with respect to the "level of knowledge required of the DM" criterion have low evaluation scores as shown in column 2 of table 2. Other factors contributing to the low ranking of these alternatives are the levels of the criterion weights and trade off parameters assigned to each criterion. As shown in table 2, the "level of knowledge required of the DM" is given the highest weight in the group. This supplements the criterion scores in determining the ranking of the alternatives. An alternative having a high evaluation score with respect to an important criterion (that is, one with high criterion weight) will be ranked high. Conversely, if an alternative is rated low with respect to an important criterion, that alternative will have a low rank. The latter contributes to the low ranking of CGT and the method of the displaced ideal with respect to the DM/analyst-related criteria shown in columns 2 and 3 of table 6. Similar reasoning can be given to the average ranking of CTP with respect to the technique-related criteria and CP and CGT with respect to the solution-related criteria (table 6).

There is also lack of consistency in the ranks of the lowest ranked alternatives across the criterion groups. Goal programming which is ranked fourteenth overall, for example, is ranked fairly high (fifth) with respect to the DM/analyst-related criteria, average with respect to the problem-related criteria and very low with respect to both technique-related (fourteenth) and solution-related (fifteenth) criteria. The concept of GP is easily understood and the technique is widely accepted for real-world application; for these reasons it is determined to be ranked above average with respect to the DM/analyst-related criteria. GP is, however, ranked eighth with respect to problem-related criteria because of its inability to handle dynamic problems as well as problems with finite number of alternatives and non-numerical data. Likewise GP is ranked very low with respect to both the technique-related and the solution-related groups of criteria. This low ranking is mainly due to its inability to get the efficient point of a multicriterion problem. Because the technique, practically solves the problems as single objective functions, that is, minimizing the sum of the deviation of the objective function values from a goal point, it cannot in its original version produce a strongly efficient solution that simultaneously satisfies the different objectives. Besides, some of the solution points in GP may be dominated points. Note that the consideration of a modified GP algorithm, a direction-based one (projecting the current point on the Pareto optimum) would alleviate this problem.

The reasons for the other low ranking alternatives can be similarly explained as well. Other factors that contribute to the ranking level of alternatives are the range of the values of the parameters used during the two-level evaluation scheme (Tecle 1988).

Conclusions

A forest watershed resources management problem is considered to be inherently a multicriterion problem that needs to be analyzed using MCDM techniques in order to arrive at a satisficing management scheme. Since there are more than 70 different kinds of MCDM techniques available, a choice of the most appropriate technique for application to a forest watershed resources management problem is important.

In this study, an algorithm has been developed for selecting from among a set of feasible MCDM techniques, the most appropriate technique for application. The algorithm is based on a first level evaluation of the techniques with respect to four different groups of criteria: (a) DM/analyst-related, (b) technique-related, (c) problem-related, and (d) solution-related criteria, resulting in the ranking of the techniques with respect to each criterion-group. Then an overall ranking of the techniques, can be arrived, in a second stage through a linear combination of the results in the first stage.

It is determined from the results that it is not appropriate to select one MCDM technique as the best for a given DM/analyst, or a given problem or for a particular solution desired. Rather, a technique can only be considered best when it is determined to be preferred through a combination of the effects of these components and the characteristics of the technique itself. In this fashion, the MCDM technique choice algorithm used in this study shows compromise programming and composite programming to be the most preferred techniques while surrogate worth trade-off method and ordinary goal programming are determined to be the least preferred ones for a forest watershed resources management problem such as the one described in Tecle (1988). The other techniques are ranked in-between these extreme rankings.

As a final remark, it should be pointed out that the MCDM technique choice algorithm discussed in this paper can be applied not only for selecting MCDM techniques to solve other MCDM problems natural resources management problems, but also to any kind of MCDM technique choice problems. To be universally and efficiently useful, however, the MCDM technique selection algorithm should be developed to include all available techniques as candidates for the selection process. In this respect extensive research on the relative performances of the techniques in solving a particular problem should be made. The technique selection algorithm can also be applied to more problems of the same type to test the effect of the analyst's bias on the choice. Lastly the technique selection algorithm should be made general enough to be applied to different types of problems. The aim should be toward the development of a handy MCDM choice algorithm for matching a particular MCDM technique to any real world multicriterion problem.

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Multiobjective Forest Management: A Visual, Interactive, and Fuzzy Approach

Lucien Duckstein, Pekka Korhonen and Aregai Tecle[1]

Abstract.--A multiobjective forest watershed resources management problem with fuzziness is formulated and then analyzed using a free search type of interactive procedure, PARETO RACE. The system enables the decision-maker to search freely any part of the efficient frontier by controlling the speed and direction of motion until an acceptable compromise solution is reached.

In this paper, a visual "free search" type of interactive multicriterion linear programming technique is applied to the management of forest watershed resources. The approach which requires no assumption on the decision maker's (DM) value function is illustrated by means of a forest watershed management experimental pilot project in the ponderosa pine forest part of the 275,000 acres Beaver Creek watershed in the Salt-Verde Basin of Arizona. There are 1,650,000 acres of ponderosa pine forest in the Basin as a whole. Based on climate and physiographic conditions (Beschta 1976, Carder 1977, Ffolliott et al. 1972), the ponderosa pine forest in this Basin can be considered as representative of the 4,282,000 acres and 11 million acres of ponderosa pine forest in the whole of Arizona and the entire southwestern United States, respectively (U.S. Forest Service 1977).

In the experimental study, alternative forest watershed schemes were carefully designed and executed to assess the range of biophysical and socio-economic effects of management practices, with the goal of selecting those practices that are likely to give the most desirable mix of benefits.

For the purposes of this study, the benefits were grouped into six objective functions, as described below; also, the results of a 5-year study from six pilot watersheds has been used for MCDM model calibration. In general, forest watersheds utilize a set of resources including land, water and labor to produce a set of goods and services such as water, herbage for animal forage, timber and recreation, and also some adverse consequences like sediment yield. In the present decision formulation, let x be an alternative decision vector and $\{z_i(x):i=1,...,I\}$ an objective function vector; then a balanced or compromis policy, also called a "satisfactum," is an acceptable trade-o between the conflicting objective functions $z_i(x)$. The problen is also subject to physical constraints, some of which are fuzzy For instance, the total area that may be subject to high percen age basal area removal is not precisely defined. Further, a objective function such as recreation may not necessarily b maximized or minimized, but it may be specified as a fuzzy goa

Background

Forest watershed management is multiobjective in natur Thus, the U.S. Department of Agriculture, Forest Service required by law to produce alternative plans that provide th multiple use and sustained yield of goods and services from th National Forest System in a way that maximizes long-term n public benefits in an environmentally sound manner (U.S Forest Service 1982). A moderate number of MCDM analyse of forest watershed management schemes may be found in th literature, being usually linear numerical objective functior and linear constraints, mostly of the goal programming typ (Arp and Levigne 1982, de Kluyver et al. 1980, Field 197 Goicoechea et al. 1976, Mattheiss and Land 1984, Schuler et a 1977, Smith and Theberge 1987, Steuer and Schuler 1978 However, fuzziness has generally not been considered.

On the other hand, several approaches have been propose to find an optimal compromise solution to a multiple objecti decision problem using fuzzy set theory (Baas and Kwakerna 1977; Bardossy et al. 1987; Bogardi et al. 1983; Chanas an Florkiewicz 1987; Nachtnebel et al. 1986; Orlovsky 198 Sakawa 1983; Sakawa and Yano 1985; Sakawa et al. 198 Siskos et al. 1984; Yager 1978; Yu 1984; Zimmermann 197 1984). The above approaches possess a common drawback: t

[1]*Duckstein is with the Case Western Reserve University, Department of Systems Engineering, Crawford Hall, Cleveland, OH 44106, U.S.A. Korhonen is with the Helsinki School of Economics, Runeberginkatu 14-16, 00100 Helsinki, Finland. Tecle is with the University of Arizona, School of Renewable Natural Resources, Tucson, AZ 85721, U.S.A.*

DM can include soft information into the model but cannot softly analyze the set of possible solutions; every time the meaning of softness must be specified *a priori* and then the technique produces a unique "hard" (so-called) fuzzy decision, without intervention of the DM. This paper attempts to develop a general approach for dealing with objectives and constraints in either a "hard" or a "soft" way, or both ways simultaneously. Fuzziness is like an objective, which may be controlled during the process. The DM can consider multiple objectives and at the same time operate with fuzzy concepts. The approach helps the DM see the impact of fuzziness on the solutions, instead of generating a unique solution.

Problem Formulation

A description of the Beaver Creek forest watershed experimental study is given in Baker (1986), Brown et al. (1974), and the U.S. Forest Service (1977), and an MCDM problem formulation thereof is presented in Tecle (1987, 1988). PARETO RACE is described in Korhonen and Wallenius (1987).

The present paper thus focuses on the fuzzy MCDM formulation and analysis. Specifically, six single period linear objective functions along with two physical (land) constraints are constructed to yield a model adapted for analysis by multiobjective linear programming. The decision variables are the size of tree basal area removal as percent (%) of total forest area as follows:

x_1 = untreated forest land (no-action option)

x_2 = forest land treated with regular 1/3 stripcut

x_3 = forest land treated with irregular 1/3 stripcut plus thinning to make an overall 50% tree basal area

x_4 = forest land treated with irregular 1/2 stripcut plus thinning to leave an overall 35% tree basal area

x_5 = forest land thinned to 25% of original tree basal area

x_6 = forest land 100% tree basal area removed.

The six objective functions are concerned with the extent of application of forest treatments for purposes of, respectively: (1) increasing water runoff on the Salt-Verde River Basin (abbreviated W. Yield in the model), (2) improving herbage production both for wildlife and livestock use (Herb. Prod.), (3) reducing sediment yield (Sed. Yield), (4) maintaining recreational benefits (Rec. Use), (5) improving economic benefits (Ec. Benef.), and (6) reducing operational cost (Oper. Cost). The problem is described by the following noncommensurable objective functions expressed in the indicated units per acre:

1. Maximize water runoff: $z_1 = \Sigma w_j x_j$, $j = 1,...,6$,

   w_j = runoff (in acre-ft).

2. Maximize herbage production: $z_2 = \Sigma f_j x_j$,

   f_j = herbage production (in lbs/acre).

3. Minimize sediment yield: $z_3 = \Sigma s_j x_j$,

   s_j = sediment yield (in tons/acre).

4. Maintain recreational use level: $z_4 = \Sigma r_j x_j$,

   r_j = recreation visitor-days in one year (RVD/acre/yr).

5. Maximize economic benefit: $z_5 = \Sigma b_j x_j$,

   b_j = return (in dollars).

6. Minimize operational cost: $z_6 = \Sigma c_j x_j$,

   c_j = expenditure (in dollars).

Each coefficient in objective function 5 is the sum of per acre dollar values of timber production, livestock production, and water yield. There are also other economic benefits that can be obtained from forested watersheds, but it is difficult to determine their monetary values at this time.

Objective function 4 is neither minimized nor maximized. "Maintaining" means that a certain aspiration is specified for the objective level, which is to be achieved as closely as possible provided that it does not cause unacceptably large losses in the other objective function values. In fact, this type of imprecise preference function may be modelled as a L-R fuzzy set membership function (Dubois and Prade 1980).

The coefficient values are given in table 1.

The problem is subject to two physical constraints. First, the whole ponderosa pine forested area in the Salt-Verde Basin is considered for treatment; hence:

$\sum_j x_j = 1.00$ the available ponderosa pine forest in the Salt-Verde Basin. The available 1,650,000 acres are taken as unity.

Second, a restriction is placed on the maximum size of ponderosa pine forested land (AM) subjected to 100% tree basal area removal. However, this constraint usually cannot be specified precisely: only a range of acceptable values can be given. If it is further assumed that the DM has a monotonically decreasing preference for increasing values of AM, varying from a fully acceptable value of AM (> 358,000 acres) to a non-acceptable value of 424,000 acres. The proportions of these values to the total available area (1,650,000 acres) are equal, respectively, to .217 and .257. This yields, for the fully acceptable value of AM, the following constraint:

$3x_5 + x_6 \leq .217$ fully acceptable level of AM. (Maximum acreage of forested land with 100% tree basal area removed or severely thinned to 25% of original tree basal area.)

Note that the proportions of AM between fully acceptable (.217) and non-acceptable (.257) are taken into account by defining a proper fuzzy set membership function.

Approach

Imprecision in the elements of the problem is modelled using fuzzy set theory. Specifically, there are two fuzzy elements in

Table 1.--Objective function coefficients.

Objective functions z_i, $i = 1,2,\ldots,6$		Type of treatment, $j = 1,2,\ldots,6$					
		1	2	3	4	5	6
Water yield	(w)	3.782	4.284	4.840	5.360	5.650	5.950
Herbage prod.	(f)	10.20	188.63	203.61	285.90	414.66	1153.17
Sediment yield	(s)	0.118	2.810	3.890	4.920	5.610	7.460
Recreational use	(r)	1.387	1.618	1.202	1.090	1.020	0.809
Economic benefit	(b)	1644	1777	3147	3225	3273	16
Operational cost	(c)	0.0	146.130	196.12	228.84	244.27	260.20

the model, for which two different types of fuzzy set membership functions may be defined.

The first imprecise feature concerns "maintaining recreational use level." Here the DM specifies an "ideal" value of recreational use level (d_r) allowing, however, either underachievement or overachievement to some extent; that is, recreational use level is modelled as follows:

$$z_4 = \Sigma r_j x_j \cong d_r$$

The DM specifies 1.4 as an ideal value for d_r and also that values in the interval [0.8,1.8] may be acceptable. This information is used to define a triangular fuzzy set membership function as sketched in figure 1. This is a special case of L-R membership function (Dubois and Prade 1980).

The above functional form of $\mu(r)$ leads to introducing the two additional technical constraints into the model:

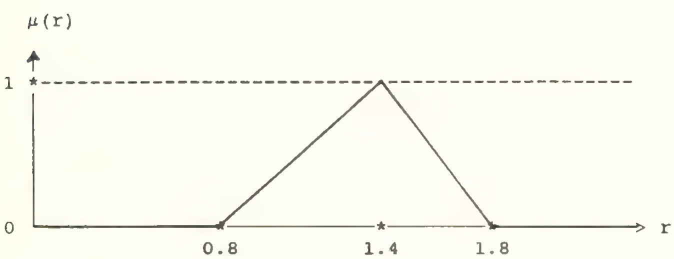

Figure 1.--Membership function of recreational use level (r).

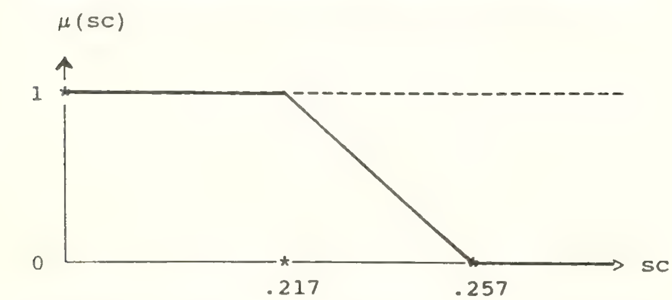

Figure 2.--Membership function of percentage area with maximum basal area removal (sc).

$$z_4 = \Sigma r_j x_j \leq 1.8 - 0.4\,\mu_r$$
$$z_4 = \Sigma r_j x_j \geq 0.8 + 0.6\,\mu_r$$

in which μ_r; $\mu_r\ \varepsilon\ [0,1]$, is now considered as a decision variable to be maximized.

The second imprecise feature introduced earlier dealt with the maximum forest acreage (AM) to be 100% tree basal area removed or severely thinned. Here, values below .217 are fully acceptable, whereas values above .257 are non-acceptable. These values are used to define a linear monotone nonincreasing membership function as sketched in figure 2.

Because of the monotone type of membership function corresponding to this constraint, one only needs to introduce into the model the following modification of the original constraint:

$$3x_5 + x_6 \leq .257 - 0.04\,\mu_{sc},$$

in which μ_{sc}; $\mu_{sc}\ \varepsilon\ [0,1]$, is taken as a decision variable to be maximized.

The final model formulation is:

$$\begin{aligned}
&\text{mx } z_1 = \Sigma w_j\text{-}x_j\\
&\max z_2 = \Sigma f_j x_j\\
&\min z_3 = \Sigma s_j x_j\\
&\max z_5 = \Sigma b_j x_j\\
&\min z_6 = \Sigma c_j x_j\\
&\max \mu_r\\
&\max \mu_{sc}
\end{aligned}$$

subject to

$$\begin{aligned}
&\Sigma x_j && = 1\\
&\Sigma r_j x_j - 0.6\mu_r && \geq 0.8\\
&\Sigma r_j x_j + 0.4\mu_r && \leq 1.8\\
&(0,0,0,0,3,1)x + 0.04\mu_{sc} && \leq .257\\
&x \geq 0 \text{ and } x \leq 1\\
&\mu_r\ \varepsilon\ [0,1]\\
&\mu_{sc}\ \varepsilon\ [0,1]
\end{aligned}$$

Next, a brief introduction to PARETO RACE is provided, and the above model is analyzed.

The PARETO RACE Approach and Application

PARETO RACE (Korhonen and Wallenius 1987) represents a dynamic, visual, and interactive procedure for multiple objective linear programming. In PARETO RACE, a DM can freely search the efficient frontier of a multiple objective linear programming problem. Specific keys are used to control the speed and direction of motion. On a display, the DM sees the objective function values in a numeric form and as bar graphs whose length is dynamically changing along the efficient frontier. The keyboard controls include gears, an accelerator, brakes, and a steering mechanism, as described in appendix 1, for easy visual interaction. The program has been initiated after the developments in Korhonen and Laakso (1986a, 1986b). The DM controls PARETO RACE by using function keys as described in Korhonen and Wallenius (1987) and explained in appendix 1. To implement PARETO RACE, an IBM/PC1 microcomputer software package called VIG (Visual Interactive Goal programming) has been developed (Korhonen 1987). The current version of the program is capable of solving problems with a maximum of 96 variables and 100 rows; up to ten rows can be objectives. Using VIG the DM can consider the problem on hand in an evolutionary way; that is, the bounds of the constraints can be modified and the role of the objective functions and constraints can be interchanged during the interactive solution process. Furthermore, intermediate solutions can be stored, and values of rows and decision variables can be viewed on the screen; thus the DM proceeds in a progressive way towards a "satisfactum." If such a "satisfactum" is not reached, the DM can return to the beginning stage and reconsider the aspiration levels of objectives and constraints, or define a new set of objectives. PARETO RACE can be rerun as many times as necessary. Further details on VIG are found in Korhonen (1987).

The application is organized in three parts. First, an approach o arrive at a perception of the problem structure is described. Second, an important objective (here, economic benefit) is elected and a trade-off between this objective and fuzziness is nalyzed. Third, a PARETO RACE including all objectives and uzziness is iteratively run until a "satisfactum" may be reached.

Perception of the Problem Structure

In Korhonen (1987), the DM becomes acquainted with the roblem structure by first stating an aspiration level vector and ien proceeding to a consistency check. An alternative approach sed in this paper consists of calculating the pay-off matrix and ie corresponding decision vectors as shown in table 2.

In table 2, the following observations may be made by the M:

- ✦ if the range of variation of an objective z_i is not large, each of the other objectives can likely be optimized at a very low "cost" to z_i,

Table 2.– Pay-off matrix and corresponding decision vectors ($\mu(r) = \mu(sc) = 1$; * refers to the optimal objective function).

Pay-off matrix:		Pay-off and decision vectors				
		1	2	3	4	5
W. Yield	≥	4.737*	4.729	4.002	4.614	4.002
Herb. Prod.	≥	237.2	405.8*	70.00	211.3	70.00
Sed. Yield	≤	3.711	3.989	.9761*	3.466	.9761
Ec. Benef.	≥	2364	1511	1785	2461*	1785
Oper. Cost	≤	180.7	177.7	42.71	174.3	42.71*
Decision vectors:						
X(1)		--	--	0.7565	--	0.7565
X(2)		0.5967	0.7026	0.1712	0.5076	0.1712
X(3)		--	--	--	0.4201	--
X(4)		0.3310	0.0804	--	--	--
X(5)		0.0723	--	0.0723	0.0723	0.0723
X(6)		--	0.2170	--	--	--

- ✦ if two vectors in the pay-off matrix are identical, such as columns 3 and 5, or almost identical, then the objectives are likely to behave similarly in the neighborhood of the marginal solutions,
- ✦ if some decision variable appears often in the decision vectors subtable, such as X(2) or X(5), this variable is likely to be present in the solution point corresponding to a "satisfactum."

Furthermore, a DM not familiar with standard features of linear programming may note that every decision vector has three non-zero components (corresponding to the common set of constraints), and that X(5) and X(6) are not non-zero simultaneously (because they appear in the same linear constraint).

If the "worst" values for objectives are too optimistic, PARETO RACE will automatically update the initial ranges when needed.

Trading off one Objective Versus Fuzziness

Consider, for example, the interdependence between economic benefit and fuzziness. To investigate this we determine the fixed aspiration levels for other objectives (water yield $\geq$ 4.1, herbage production $\leq$ 300, sediment yield $\leq$ 3, and operational cost $\leq$ 130) and consider trade-offs between $\mu(r)$ and economic benefit with different values of $\mu(sc)$. The solution values at points of basis changes are given in table 3, where values of $\mu(r)$ smaller than 0.67 (in the last column) have no influence on the solution. Other solution values may be obtained by linear interpolation.

Table 3 shows that economic benefit does not appear to be very sensitive to the fuzzy parameter $\mu(sc)$. In contrast, this benefit is strongly influenced by the fuzzy function $\mu(r)$: in fact, as $\mu(r)$:0 1, the benefit function takes on roughly 42% of the

Table 3.--Sensitivity of economic benefit to fuzziness.

μ(sc)	μ(r) and solution values			
1.00	Ec. Benef.	1548.7	1785.8	1950.6
	μ(r)	1.0000	0.8215	0.6743
0.75	Ec. Benef.	1549.6	1782.1	1951.2
	μ(r)	1.0000	0.8250	0.6739
0.50	Ec. Benef.	1550.6	1778.4	1951.8
	μ(r)	1.0000	0.8285	0.6736
0.25	Ec. Benef.	1551.5	1774.6	1952.4
	μ(r)	1.0000	0.8320	0.6732
0.00	Ec. Benef.	1552.4	1770.9	1953.0
	μ(r)	1.0000	0.8355	0.6728

variation shown in the pay-off matrix (table 2). It means that letting recreational use stay at its ideal level is rather costly from the economic benefit point of view. In addition, the bound for sediment yield is binding after the first basis changes, and operational cost is not binding anymore after the second basis change. Obviously, herbage production is critical in trying to improve economic benefit. A broader perspective will now be sought by considering all objectives simultaneously.

Complete PARETO RACE

Now all "actual" objectives and fuzzy parameters--also taken as objectives--are considered and the subspace of reasonable solutions examined by using PARETO RACE. Figure 3 shows a sample solution and table 4 gives a set of five reasonable solutions; each of these solutions may be selected as a satisfactum by the DM.

From table 4, we see that variables X(1), X(5), and X(6) are present in all solutions. The presence of other variables depends on how much relative emphasis is placed on each of the six objectives.

Discussion and Conclusions

This investigation follows an interactive visual approach to trading off conflicting objectives, as recommended in Loucks

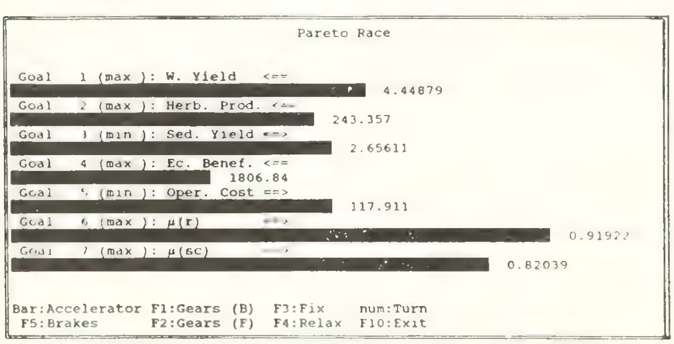

Figure 3.--An example of PARETO RACE screen.

Table 4.--A set of possible compromise solutions determined using PARETO RACE.

	Payoff and decision vectors				
	1	2	3	4	5
W. Yield	4.465	4.588	4.598	4.581	4.349
Frg. Prod.	300.0	309.0	303.9	264.1	199.1
Sed. Yield	2.942	3.041	2.934	2.651	2.041
Ec. Benef.	1549	1821	1882	1882	1882
Oper. Cost	130.0	130.0	122.4	107.0	84.61
μ(r)	1.000	.7600	.6748	.6854	.7732
μ(sc)	1.000	.7600	.4925	.0000	.0000
Rec. Use	1.400	1.257	1.206	1.211	1.264
Max. Rem.	0.217	0.227	0.237	0.257	0.257
Decision Vectors:					
X(1)	0.2622	0.3621	0.4422	0.5549	0.6165
X(2)	0.5178	0.1519	--	--	--
X(3)	0.0417	0.2878	0.3505	--	0.2246
X(4)	--	--	--	0.2623	--
X(5)	0.0194	0.0142	0.0150	0.0371	0.0490
X(6)	0.1588	0.1840	0.1923	0.1457	0.1099

and Fedra (1987), and illustrated in, for example, Okada et al. (1985). Specifically, here, forest watershed management has been formulated as a multiple objective linear programming problem; imprecision in either an objective function or a constraint has been introduced into the model by using fuzzy set membership function μ as a variable to be maximized, as suggested in Korhonen et al. (1987a). In order to trade off objective function values and μ, a "free" search type of interactive method called PARETO RACE has been applied. The advantages of such an approach are that:

- no value function needs to be elicited from the DM,
- no norm (such as an L_p-norm) needs to be defined,
- no aggregation rule for membership functions needs to be specified.

The disadvantage of such an approach is inherent to all unstructured MCDM-techniques; namely, that the rate of convergence toward a "satisfactum" cannot be guaranteed. This problem is discussed in Korhonen et al. (1987b), where DM's were sometimes observed to consider the same alternatives as best repeatedly but in any case stopped the search process very quickly.

The novelty in the present approach is an evolutionary viewpoint consisting of the following three steps:

1. acquiring a perception of the structure of the model to facilitate subsequent interactive analysis,
2. trading off one important objective at a time with one or more measures of imprecision,
3. proceeding to a complete analysis to obtain an overall view of the decision problem and to arrive at a "satisfactum."

Step 1 points out to the DM which decision variables are important and how the objective functions are related. This step may also provide a tutorial on certain properties of linear programming.

Step 2 gives a view on the sensitivity of important objectives to fuzzy elements of the model. Thus, in the case study, the economic objective exhibits substantial sensitivity to fuzzy membership function $\mu(r)$ representing acceptability of maintaining a given recreational use level. In contrast, this economic objective function exhibits very little sensitivity to $\mu(sc)$ representing acceptability of maximum area that may be subject to high percentage tree basal area removal.

Finally, step 3 provides a combined "hard" and "soft" analysis of the complete problem, and yields a set of reasonable compromise solutions; this step, as observed before, should lead to a "satisfactum" after a small number of iterations. This approach thus seems to represent a promising tool for analyzing forest watershed resources management problems subject to imprecision, a situation prevalent in many forest watershed management objectives.

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Appendix 1

Keyboard Controls of PARETO RACE

(SPACE) BAR: "Accelerator"	
	Proceed in the current direction at constant speed.
F1: "Gears Backward"	
	Increase speed in a backward direction.
F2: "Gears Forward"	
	Increase the speed in a forward direction.
F3: Fix	
	Take the current value of a specified goal as an unconditional bound.
F4: Relax	
	Release the unconditional bound of the fixed goal set earlier.
F5: "Brakes"	
	Reduce speed.
num: "Turn"	
	Change the current direction of motion by pressing the goal's corresponding number key once or several times.
F10: Exit	
	Return to the main menu.

The use of PARETO RACE is like driving a car on an n-dimensional ($n \leq 10$) road. The driver can use gears, accelerator and brakes, and steer by pressing the keys of an IBM/PC1.

Predicting Individual Log Dimensions and Grade from Hardwood Cruise Data

Daniel A. Yaussy and Robert L. Brisbin[1]

Abstract.--The software described allows the estimation of board-foot volume and numbers of logs by log grade in a hardwood stand based on cruise data. A two-stage estimation procedure was developed using regression techniques and linear discriminant analysis. A bucking simulator is then used to calculate the scaling diameter and length of each log.

STUMP, a System of Timber Utilization and Mill Processing, is being developed as a software package that incorporates hardwood timber quality in the estimation of yield and value from the stump through the mill. This program is an integrated software package that consists of four modules and data entry routines which use standard timber cruise or log scale entries plus the quality measures of tree or log grade (Hanks 1976, Rast et al. 1973) to estimate yield and value by log and lumber grade. There are many programs on the market that process and summarize hardwood cruise data, yet few of these programs incorporate a measure of tree quality as an input. This usually means that an accurate estimate of intermediate or end-product distribution is lacking. This, in turn, limits the effectiveness of the program in providing an adequate estimate of the value of the resource. The development of STUMP is partially funded by a grant from the Forest Resources Systems Institute (FORS)[2] to integrate quality-related research into a package that can be used to evaluate the impact of tree and log quality on the value and volume of intermediate and end products.

The first module of the system is used for woodland inventory and timber appraisal. Output consists of volume and value estimates by species and end product (i.e., lumber grade and veneer). The second module uses the same tree cruise data and estimates the size and grade of logs produced by each tree. The information is summarized by length, scaling diameter, and log grade for each species along with an estimate of stumpage or delivered price. In the third module, log scale information from the second module or from actual log scale data will be used to maintain mill yard inventory by quality classes and to estimate end product yields. The fourth module will monitor production and maintain end product inventory records. Landowners, service foresters, consultants, loggers, and sawmill managers will find STUMP useful for estimating their timber resource.

Module 1 uses existing hardwood tree grade equations to predict expected lumber grade yields from graded trees (Hanks 1976, Hanks and Brisbin 1978). Log grade equations have been developed for predicting lumber grade yields from log characteristics (Howard and Yaussy 1986, Yaussy 1986, Yaussy 1987, Yaussy and Brisbin 1983) and are used in Module 3. Module 2 uses newly developed models to predict merchantable log yields and sizes from tree cruise data. The remainder of this paper focuses on the development of Module 2.

Developing Models for Module 2

The purpose of the second module is to provide information about the size, quality, and value of sawlogs and veneer logs that can be produced from a tract of timber (the procedures in this section are described in detail in Yaussy et al. 1988). An estimation of the number and volume of cut logs that can be produced from a tract of timber along with diameter, length, and grade distributions will be useful to the seller, logger, or purchaser of the tract. Independent loggers can use the information to more accurately define production costs and to estimate stumpage or delivered log values, and mill managers can estimate the quantity and quality of logs that would be added to their mill yard inventory from a timber sale.

New research was needed to describe the relationship between log quality and size and tree quality and size. We determined that the best approach would be to estimate the Interna-

[1] *Research Forester and Research Forest Products Technologist, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, Delaware, Ohio.*

[2] *This project was partially funded by the Forest Resources Systems Institute, which receives Federal financial assistance. Benefits of the Forest Resources Systems Institute are available to all eligible persons regardless of sex, race, color, national origin, religion, handicaps, or age.*

tional one-fourth inch gross board-foot volume distribution by log grade and the distribution of bucked logs by log grade. These two quantities are highly correlated. A two-staged estimation procedure was developed to take advantage of this correlation. The first stage estimates the volumes by log grade. The second uses these estimated volumes to help predict the numbers of bucked logs by log grade.

To increase user acceptance of these models, only variables commonly collected in a tree cruise were utilized:

1. Species.
2. Diameter at breast height, in inches (D).
3. Merchantable saw log height (H) defined as the height in 16-foot logs and half logs to the small end of the highest bole section which would produce a grade 3 log.
4. USDA Forest Service hardwood tree grade.

Tree grade may not be a truly common variable in hardwood tree cruises; however, it is the least that is required to achieve any differentiation of quality in log grades.

Since the volumes of the three log grades must sum to the total merchantable sawlog volume, these volumes are not independent of each other. This interdependence indicated that multivariate regression was the appropriate technique to model these relationships. The difference in volume distribution due to the differences in tree grade was accounted for by the use of dummy variables. The full volume estimation model from which the individual species models are derived is large and complex:

$$\begin{aligned} V_i &= b_{i0} + b_{i1}D + b_{i2}D^2 + b_{i3}H + b_{i4}DH + b_{i5}D^2H \\ &+ b_{i6}G_2 + b_{i7}DG_2 + b_{i8}D^2G_2 + b_{i9}HG_2 + b_{i10}DHG_2 \\ &+ b_{i11}D^2HG_2 + b_{i12}G_3 + b_{i13}DG_3 + b_{i14}D^2G_3 \\ &+ b_{i15}HG_3 + b_{i16}DHG_3 + b_{i17}D^2HG_3 \end{aligned} \quad [1]$$

where

V_i= gross International one-fourth inch board-foot volume for log grade i, i=1,2,3

G_k= dummy variable indicating tree grade, k=2,3:

Tree grade	G_2	G_3
1	0	0
2	1	0
3	0	1

b_{ij}= coefficients determined by regression, j=0,...,17.

It was originally intended that the same reduced model form would be used for all species with the species differences accounted for with the different sets of coefficients; however this method did not produce models with adequate precision. Therefore, the full model [1] was reduced by a process of backward elimination for each species. This involved the elimination of the least significant variable, then rerunning the reduced model. This process was repeated until all remaining variables were statistically significant at an .05 implied level of significance. This produced a different model for each of the 11 species modeled (table 1).

Table 1.--Species substitution used in application of models in Module 2.

Species for which models have been developed	Species groups for which Module 2 assigns substitutes
Basswood (BAS)	Cucumber
	Magnolia
Black cherry (BLC)	Ash
	Black walnut
Black oak (BLO)	Misc. red oaks
	Southern red oak
	Scarlet oak
Chestnut oak (CHO)	
Northern red oak (NRO)	Cherrybark oak
Paper birch (PAB)	
Red maple (REM)	Misc. soft hardwoods
	Silver maple
	Hickory
	Pecan
	River birch
Sugar maple (SUM)	Misc. hard hardwoods
	Beech
White oak (WHO)	Misc. white oaks
Yellow birch (YEB)	Sweet birch
	Elm
	Cottonwood
Yellow-poplar (YEP)	Aspen

Trying to estimate the distribution of bucked logs by log grade presented the problem of predicting a discrete variable. Linear discriminant analysis develops equations which can be used to estimate the probability that an observation fits into a certain category. In this instance, the categories were the numbers of logs of each log grade that a tree will produce (i.e., 0, 1, 2, 3, 4). This meant that there might be an equation for each possible category in each of three log grades, in each of 11 species, 198 equations. With this in mind, it was decided to limit the number of variables in each equation to five. The linear discriminant function used for each species was:

$$\begin{aligned} f_{in} &= a_{in0} + a_{in1}G_2 + a_{in2}G_3 + a_{in3}V_1/D^2 + a_{in4}V_2/D^2 \\ &+ a_{in5}V_3/D^2 \end{aligned} \quad [2]$$

where

f_{in} = linear discriminant function value for log grade i and number of logs n, n=0,...,4

a_{inm} = coefficients determined by discriminant analysis, m=0,...,5

The model form [2] was the same for each species, but each has its own set of coefficients.

One-quarter of the data available were set aside to be used as a validation data set. The multivariate equations [1] were applied to the trees in the validation data set. The results (fig. 1a)

indicate that total merchantable volume by species is predicted within 5% of the actual. All log grade volumes are within 20% except for log grade 3 chestnut and northern red oaks. These cells had relatively low numbers of logs in both the development and validation sets compared to the rest of the volumes for other grades of those species.

Actual log grade volumes of the validation trees were used as input to the discriminant functions [2] for testing. The total predicted numbers of logs is within 10% for all species except one, and is very acceptable for each log grade within species, except for grade 3 northern red oak (fig. 1b). It is interesting that the multivariate equations [1] overestimated the grade 3 volume for this species by such a wide margin, yet the discriminant functions [2] underestimated the number of logs by the same percentage. This might be due to the low number of grade 3 northern red oak logs in the study.

For the predicted values that deviated from the actual, the deviations are usually negative. This is due to the nature of the system being modeled. The probability of a tree producing no logs or one log of a certain grade is much higher than the probability of producing two, three, or four logs of that grade. And this model, like most models, tends toward the mean and avoids the extremes. This yields a slight negative bias even when the model is used with the development data set.

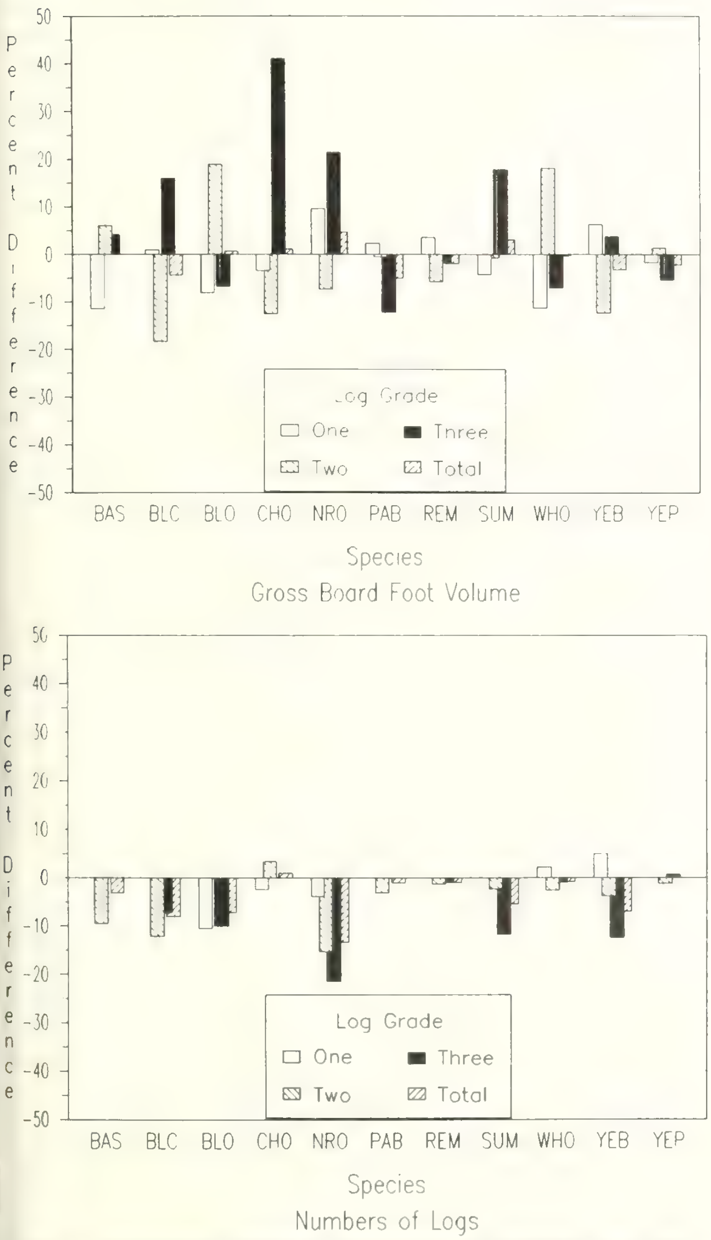

Figure 1.-- **Differences between actual values of validation data set and those predicted by the models developed for Module 2 of STUMP: (a) gross board-foot volume; (b) numbers of logs.**

Applying the Models

The models were developed for only 11 species. Module 2 has a species substitution list that allows for the input of 32 separate species groups (table 1). For some trees, the use of the two models will produce seemingly contradictory results (e.g., log grades with volumes but no estimated logs). This inconsistency occurs because regression equations almost always result in a nonzero volume estimation for each grade. A model form like that presented by Reed et al. (1987) would not produce these results.

The estimated volume can be one of three classes:

1. Large enough to produce a positive number of logs when fit into the discriminant functions.
2. Too small to produce a positive number of logs.
3. A small negative volume resulting in zero logs for that log grade.

Figure 1a indicated that the volume equations are fairly unbiased across species. If the small volumes were dropped, the overall estimate for the cruise would be negatively biased. Therefore, the program adds the unused volumes associated with zero logs to the next tree of the same species. This also provides for the occasional grade 1 log produced from a grade 3 tree.

The next step in the program is to take the estimated numbers of logs and adjusted volumes and "buck" the tree. The Forest Service log grades provide specific guidelines as to minimum log lengths and scaling diameters for each log grade. With this information, dbh, volume, number of logs, and an estimate of taper, the log dimensions can be estimated. Specific taper equations developed for the majority of the species require that total height be measured for each tree. This is not a realistic option on a timber cruise. A general "rule of thumb" taper was incorporated into the program. The International scaling taper of 2 inches per 16 feet was assumed, but this was not enough. Carl Mize[3] has suggested that 2 1/2 inches taper per 16 feet is more realistic for hardwoods. It works well in this case after it

[3]Cited in "What to cut: logs or pulp?", Forest Industries magazine, June 1987, p. ES5.

was adjusted to fit the average Girard Form Class from the data for each species and tree grade. Another assumption made for the program is that the highest grade material occurs in the butt portion of the tree.

The program provides for the input of a veneer bolt length for each tree. When a veneer bolt is present, the small-end diameter and International volume are calculated. Then if the veneer length is less than 16 feet, one of the estimated logs of the highest grade present is deleted and the volumes adjusted accordingly. If the veneer length exceeds 16 feet, two logs are deleted. Small-end diameters and log lengths are calculated for the remaining logs in each log grade. Volumes are then recalculated for each log by fitting the estimated diameters and log lengths into either the Doyle or International scaling rule. If an estimation of cull was input for the tree, it is assigned to each log and bolt produced by that tree and a net volume figure is calculated.

The data set used to validate the models was again used to validate the program calculations. The difference between the actual volumes, numbers of logs, average scaling diameter, and average log lengths and the results of the Module 2 calculations are presented in figures 2a-2d as percentages by log grade for each species. Total volume across log grades is within 10% for each species except for yellow poplar (14%). Individual log grade volumes by species are within 25% for all but grade 3 chestnut oak. The same bounds hold for the predicted numbers of logs except for the addition of grade 1 yellow birch. The graphs for average scaling diameter and log length are much less variable than the previous two graphs. Almost all average diameters are within 10%, while all but two average log lengths

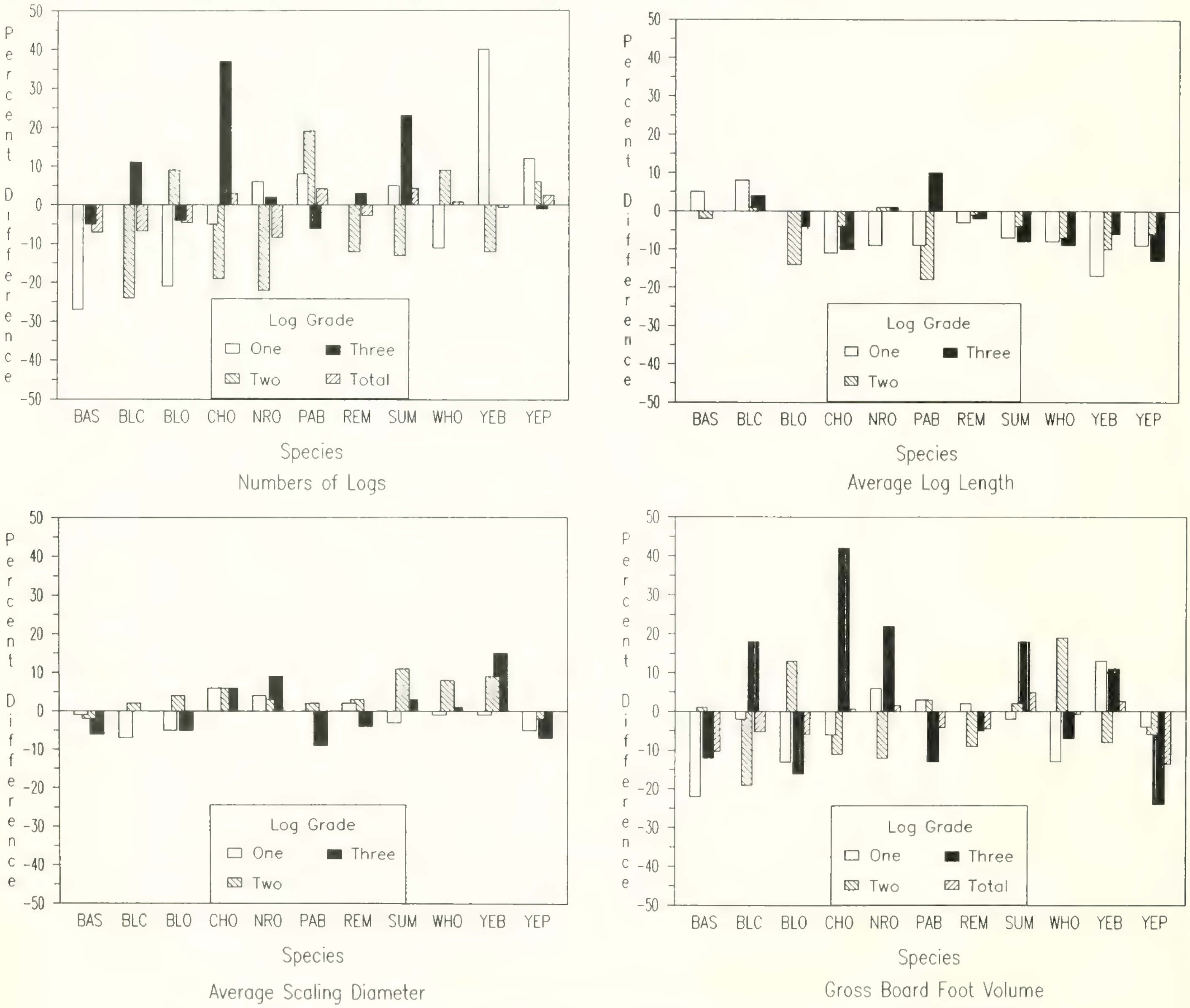

Figure 2.-- Differences between actual values of validation data set and corresponding results from Module 2 of STUMP: (a) numbers of logs; (b) average scaling diameter; (c) average log length; (d) gross board-foot volume.

Table 2.--Sample output from Module 2 of STUMP.

Veneer/Bolts	Total	Per acre	Std. Err.	Confidence interval	
Number of logs	6	2	093	1	2
Gross int. bf vol.	1117	279	16.382	247	311
Net int. bf vol.	1092	273	16.016	241	304
Delivered Price($)	997	249	15.184	219	279

Grade 1 logs	Total	Per acre	Std. err.	Confidence interval	
Number of logs	78	20	.530	18	21
Gross int. bf vol.	12489	3122	74.977	2975	3270
Net int. bf vol.	12427	3107	74.541	2960	3253
Delivered Price($)	2538	634	18.007	599	670

Grade 2 logs	Total	Per acre	Std. err.	Confidence interval	
Number of logs	221	55	1.384	53	58
Gross int. bf vol.	22027	5507	125.043	5261	5752
Net int. bf vol.	21672	5418	122.945	5176	5660
Delivered Price($)	2571	643	14.629	614	672

Grade 3 logs	Total	Per acre	Std. err.	Confidence interval	
Number of logs	296	74	2.081	70	78
Gross int. bf vol.	17112	4278	107.237	4067	4489
Net int. bf vol.	16805	4201	105.160	3995	4408
Delivered Price($)	1425	356	8.860	339	374

		Veneer					Grade 1				Grade 2					Grade 3				
	LENGTH	≤8	10	12	14	16≥	10	12	14	16	8	10	12	14	16	8	10	12	14	16
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	35	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	23	4	18
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	18	0	9	11
	11	0	0	0	0	0	0	0	0	0	5	16	16	0	18	0	18	0	4	9
S	12	0	0	0	0	0	6	0	0	0	20	7	4	3	8	10	0	9	12	4
C	13	0	0	0	0	0	15	7	0	0	6	2	8	3	7	3	6	2	0	4
A	14	0	0	3	0	0	4	0	3	6	3	12	0	3	8	5	2	0	0	2
L	15	0	0	0	0	0	0	0	0	3	3	4	3	4	3	2	4	5	0	2
I	16	0	0	0	0	0	0	2	0	0	0	5	0	2	4	2	0	2	0	0
N	17	0	0	0	0	0	0	2	2	2	2	0	0	3	6	2	1	0	0	0
G	18	0	0	0	0	0	0	2	0	2	2	0	0	2	0	9	0	1	1	0
	19	0	0	0	0	0	1	0	0	6	5	2	2	1	0	2	2	2	0	0
D	20	0	0	0	0	0	1	0	0	2	5	4	0	0	1	1	0	0	0	0
I	21	0	0	0	0	1	0	2	0	0	3	0	0	0	0	0	0	0	0	0
A	22	0	0	0	0	0	1	2	0	0	1	0	0	2	0	1	1	0	0	0
M	23	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0	0	0
E	24	0	1	0	0	0	0	0	0	3	1	0	0	0	1	0	0	0	0	0
T	25	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E	26	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R	27	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	32+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

are within 15%. There is, however, a noticeable negative bias in the log lengths, though it does not seem to carry through to the volume estimates.

Program Output

Module 2 is designed to accept four types of sampling schemes: (1) 100% inventory, (2) point-sampling cruise, (3) fixed-plot cruise, and (4) strip cruise. The number and volume of the logs are adjusted accordingly. The major output of Module 2 is a summary by species groups of volume, value, and a diameter/length distribution by log grade (table 2). This can be routed to the printer, a disk file, or both. A user-modified file contains prices, in dollars per thousand, for each log grade and veneer class for each species group. These prices, Doyle or International, can be stumpage, delivered log, or any other price the operator wants to use.

A log file is an optional output which contains a listing of the species, scaling diameter, log length, cull proportion, and log grade of each estimated log produced from the stand. This file can be used for further analysis and it is in the format of input for Module 3. No graphics are provided by Module 2; however, an optional graphics file containing summaries of volume, value, and numbers of logs is available for use with other packages.

Program Availability

STUMP is designed to work on MS-DOS machines with at least 256K RAM, two floppy disk drives, or one floppy and one hard disk. The entire STUMP software package should be completed by the fall of 1988. The user's guide should be completed by January 1989. FORS will handle distribution and support of the package.

Future Applications

There are tentative plans to incorporate parts of STUMP into individual tree hardwood growth and yield simulators such as OAKSIM (Hilt 1985), and possibly into some form of harvest simulator. This would provide these packages with improved economic estimates to aid in the development of management guidelines.

Since STUMP is mostly written in FORTRAN, it is our intention to produce a Data General version to be used by the National Forest Systems of the Forest Service.

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Designing An Optimal Wood Utilization System Using a De Novo Programming Approach

Guillermo A. Mendoza and B. Bruce Bare[1]

Abstract.--Describes a de novo programming approach to production planning in the forest products industry. Unlike traditional models which optimize suboptimal systems with a given set of resources, the de novo approach focuses on designing optimal systems where resource constraints are designed optimally.

Efficient utilization of raw materials has been a long-time concern of the forest products industry. Here, efficiency is measured not only in terms of increased product yield per unit input, but also in economic terms. Several techniques have been developed to achieve economic efficiency in wood products utilization. Most notable among these are the use of mathematical models like linear programming (Carino 1986, Mendoza and Bare 1986), dynamic programming (Faaland and Briggs 1984, Pnevmaticos 1972), simulation (Galbraith and Meng 1981, Treiber and Boyle 1980, Wagner and Taylor 1983), and queuing theory (Carino and Taylor 1982, Maurer 1968). Successful application of some of these techniques also has been reported (Eng et al. 1986, Hay and Dahl 1984, Lembersky and Chi 1984, Bare et al. 1984).

One of the major limitations of these models is that they are designed primarily to determine optimal solutions to prespecified problems. In general, these models optimize systems with given sets of fixed resources. However, in real world planning problems, resources often are not fixed, but can be changed depending upon their economic value, marketability, or overall contribution to the production system. Hence, the production planning problem should not viewed as simply a problem of determining an optimal output schedule for an assumed fixed level of production inputs. Instead, the scope of planning must be enlarged to encompass the design of an optimal system where the production inputs are not specified *a priori* as fixed, but must be optimally designed. The question should be, "What kind, and how much, of each resource should be acquired so that the resulting production system yields the best returns?"

[1]*Assistant Professor, Department of Forestry, University of Illinois, Urbana, IL 61801; and Professor, College of Forest Resources and Center for Quantitative Sciences in Forestry, Fisheries and Wildlife, University of Washington, Seattle, WA 98195.*

The forest products industry is a natural environment for testing this approach to production planning. Wood utilization planning--from the primary processing of raw materials to the manufacture of final products--is a production-intensive system where a variety of inputs are used at various stages of production. Given such highly productive systems, an underutilization of raw materials, or an inefficient allocation of production inputs may result in substantial increases in production costs and less profit. Thus, it is important that all resources be efficiently allocated during the planning process.

This paper examines the use of de novo programming in a wood utilization context, and illustrates the design capabilities of the model with a sample problem. De novo programming is used because it offers the capability of designing optimal production systems within given budgetary limitations.

De Novo Programming

This section summarizes the de novo approach, particularly its methodology as it relates to linear programming (LP). This approach recognizes that not all constraints are "hard" (i.e., fixed) and, hence, not subject to change. Instead, some constraints are assumed to be "soft;" to be determined through analysis. Thus, using de novo programming, the optimal production schedule is simultaneously determined with the right hand sides of the soft constraints.

Zeleny's (1986b) External Reconstruction Algorithm (ERA) is an example of a de novo algorithm which can solve a range of problems. The algorithm takes advantage of the fact that only binding constraints characterize optimal solutions to LP problems. Thus, initially, there is no need to work with all constraints. Instead, the ERA is used to reconstruct all fixed, and

potentially binding constraints while determining the optimal levels of the soft constraints.

The ERA is an iterative algorithm which works through the use of an aggregate constraint which (initially) consists of: (1) all fixed inequality constraints to be reconstructed during subsequent iterations, (2) all soft inequality constraints to be designed, or (3) a combination of the above. All equality constraints are taken as fixed and are excluded from the aggregate constraint.

At each iteration of the ERA, the most violated fixed inequality is decoupled from the aggregate constraint and a new LP is solved. The new problem consists of one additional fixed constraint (the one decoupled) and the revised aggregate constraint. This process of decoupling and resolving is continued until all of the fixed inequalities are satisfied. Then the optimal levels for the soft constraints being designed are also available.

A full description of the ERA is available in Zeleny (1986a, 1986b) and an application of this approach to land management planning is described by Bare and Mendoza (1988).

Sample Problem

To demonstrate the use of de novo programming in designing an optimal wood utilization system, a sample problem adapted from Pearse and Sydneysmith (1966) is used. This sample problem was selected because it is simple enough for illustrative purposes and yet it is representative of the nature of production planning problems present in the forest products industry. Some aspects of the sample problem such as (1) the conversion or recovery rates for different primary and secondary processing, (2) the production costs, and (3) the prices of finished products are notably dated. However, for the purpose of this paper, which is primarily to illustrate the methodology of de novo programming, it was deemed unnecessary to update these coefficients.

The problem described by Pearse and Sydneysmith (1966) involves the allocation of a fixed quantity of coniferous logs to several interdependent conversion facilities, where the objective of the allocation is to maximize the net value of the resources. The problem involves the allocation of 12 primary inputs (i.e., species and grade-dependent log types) to 35 intermediate and 59 final activities. The intermediate activities consists of log sawing (producing lumber, chips and hog fuel), log peeling (producing veneer, chips and hog fuel) and log chipping (producing chips). The final activities consists of plywood, pulp, lumber, and hog fuel.

In their formulation, no physical limitations are imposed on the productive capacities of the conversion facilities. Thus, a long term view of production planning is adopted. Further, the problem is structured and solved as a regional solution and is not specific to an individual firm. As shown below, this long-term view fits the framework of de novo programming very closely as the latter is most useful when resource capacities are viewed as variable and subject to design.

For a more detailed description of the sample problem, readers are referred to Pearse and Sydneysmith's (1966) paper. To highlight the design capabilities of de novo programming various cases--each revolving around the Pearse and Sydneysmith model--are presented.

Case I. Optimizing a Given System

This case illustrates the traditional concept of optimization using LP where all constraints are collectively treated as fixed or given. The problem described in Pearse and Sydneysmith (1966) is slightly modified for this and subsequent cases by imposing some demand and market restrictions for lumber products. Demand restrictions are specified as minimum levels of production required in order to meet the obligations of the region to its consumers. A minimum level of 2 million cubic feet is specified for all lumber products. Likewise, market restrictions are specified to limit the maximum amount of product that the market can absorb. This is specified as 50 million cubic feet for all lumber products. With these modifications, the problem solved is identical to that described in the original paper.

To simplify the presentation of results, only the right-hand-sides (i.e., resource use) and objective function values associated with the various solutions are presented. However, this information is adequate for describing the advantages of "designing an optimal system" rather than optimizing a given system.

Table 1 shows the "given" amount of resources (i.e., log availability) and their corresponding usage. The results in Case I suggest that all log types have been utilized, and that the maximum profit is \$319.04 million[2]. Given this information, one may wonder if it pays to buy additional logs, assuming that a log market is available.[3] Exploring this possibility of log purchase further, the next question is how much of each log type should be bought? This question then brings out the idea of "designing the optimal amount " of resource inputs--in this case the optimal amount of each log type. The design problem therefore is not how to optimize the returns from a "given" production system with fixed resource inputs, but rather how to determine the optimal level of resource inputs. Hence, the right-hand-side (RHS) value is no longer fixed but is considered "soft."

Case II. Designing an Optimal System

The problem used in this case is the same problem used in Case I. However, instead of assuming a fixed distribution of log

[2] The optimal profit from Pearse and Sydneysmith (1966) was \$325.5 million. The difference is due to the added demand and market restrictions for lumber.

[3] The shadow prices of the log availability constraints provide this information. However, they assume that each RHS is changed sequentially. De novo programming permits all RHS's to be altered simultaneously.

Table 1.--Log availability and allocation for Case I (million ft³).

Log grade and species		Log type	Log availability	Log allocation
D. fir	#l plr	1	6.1	6.1
	#2 plr	2	14.2	14.2
	#3 plr	3	28.4	28.4
	#4 plr	4	18.3	18.3
	#2 swlg.	5	46.7	46.7
	#3 swlg.	6	89.5	89.5
Hemlock	#l swlg.	7	13.8	13.8
	#2 swlg.	8	50.0	50.0
	#3 swlg.	9	213.6	213.6
Spruce	#l swlg	10	1.3	1.3
	#2 swlg.	11	11.4	11.4
	#3 swlg.	12	19.8	119.8
	Total		513.1	513.1

Optimal profit = $319.04 million.

inputs as described in table 1, it is assumed that the log input availability is flexible and can be designed (i.e., the optimal volume by log-type is to be determined).

The "hard" constraints consist of those that must be satisfied. In this case, all the material balance equations describing the input-output flow of intermediate to final products are considered hard.

The "soft" constraints consist of those related to log inputs. Before presenting the aggregate constraint, it should be pointed out that the problem addressed in Case II is modified from Case I. That is, the question now is "what should be the optimal level of each log type?" It is therefore assumed initially that any additional log type can be obtained either by purchasing them from a regional log market or from another region.

The other question that is addressed is "what are the limits to the design problem," or "what are the criteria for designing the system?" One logical criterion is budget. That is, the cost of each log type is specified and logs are purchased subject to this limitation. For this problem, the cost schedule used is described in table 2.

The aggregate constraint can now be described as:

$$\sum_{j=1}^{n} \left(\sum_{i=1}^{\Omega} a_{ij} X_j \right) \leq 13.455 \text{ (\$ million)}$$

where Ω is the set of "soft" constraints.

The aggregate constraint simply states that a limited budget of $13.455 million is available for log purchase. Using this dollar amount allows comparison of the solutions obtained in Cases I and II. Note that the difference between Cases I and II is the addition of the aggregate constraint in lieu of the "fixed" log input levels described in Case I. All the other "hard" constraints are the same for both cases. The solution for Case II is summarized in table 3.

Table 2.--Cost schedule for various log types.

Log type	Cost[1] *(100 ft³)*	Log availability *(million ft³)*	Total purchase Cost *($ million)*
1	54	6.1	3.294
2	49.5	14.2	7.029
3	45	28.4	12.780
4	35	18.3	6.405
5	27	46.7	12.609
6	24.75	89.5	22.151
7	22.5	13.8	3.105
8	20.25	50.0	l0.125
9	23.25	213.6	49.662
10	27	1.3	.351
11	22.5	1.4	2.565
12	23.25	19.8	4.4737
	Total purchase cost		13.455

[1]Costs were estimated at about 75% of log selling prices described in Pearse and Sydneysmith (1966).

Table 3.--Optimally designed resource inputs.

Log type	Optimal RHS design *(million ft³)*
1	0
2	0
3	0
4	0
5	330.14
6	0
7	0
8	22.22
9	0
10	151.51
11	0
12	0
Total	503.87
Optimal profit =	$485.23 million.
Total purchase cost =	$13.5 million.

The solution from table 3 shows the optimal design of the system includes; 330.14 million cubic feet of log type 5; 22.22 million cubic feet of log type 8, and 151.51 million cubic feet of log type l0. Comparing the two solutions shown in tables 1 and 3 reveals that 9.23 million cubic feet less are required to produce a total increase in net returns of $166.2 million. And, both solutions satisfy the budget constraint. This presents an interesting situation. However, one might ask if the recommended amount of log types 5 and 10 can be obtained from the log market at the assumed constant costs shown in table 2.

To extend Case II, further analysis was made by placing a restriction on the maximum amount for log types 5 and 10 of 100 and 200 million cubic feet, respectively. Given this restriction, the optimal RHS design is given in table 4. Now, log type 8 drops out of solution and is replaced by log types 1 and 7.

Table 4.--Optimal design given restrictions on log market.

Log type	Optimal RHS design *(million ft^3)*
1	19.03
2	0
3	0
4	0
5	100
6	0
7	192.3
8	0
9	0
10	200
11	0
12	0
Optimal profit =	$385.78 million.
Total purchase cost =	$13.5 million.

Case III. Multi-Criteria Optimal Design

Moving from the single criterion situation in Cases I and II, Case III illustrates the problem of designing an optimal system when two or more objectives exist. Case II illustrated how to design an optimal system with only one objective. Now, to demonstrate a multicriteria optimal design situation, the sample problem is slightly modified to include a second objective. This objective involves the minimization of total processing costs for lumber, veneer, and chips.

In multi-objective programming (MOP) the concept of "ideal solution" is often utilized. This is a solution where all objectives are simultaneously optimized. In traditional MOP (i.e., where the constraints are collectively treated as fixed), the "ideal solution" is, in general, infeasible. However, if some of the constraints can be considered "soft" or "flexible" (i.e., under a de novo formulation), it is conceivable that the "ideal solution" may be made feasible through reallocation or design of the soft RHS. This problem is examined in Case III.

The results from the analysis indicate that the "ideal solution" shown in table 5 is indeed infeasible when the RHS are not designed. Thus the maximum profit can not be achieved while simultaneously minimizing costs. Furthermore, even using a de novo formulation (i.e., where the RHS of the log inputs are designed), the "ideal solution" is still infeasible. This suggests that the ideal values of the two objectives cannot be attained merely by designing the "soft" constraints. The other set of constraints (i.e., the "hard" material balance equations, the demand and market restrictions, and the additional constraints requiring the values of the objectives to be at their ideal values), are collectively, causing the infeasibility of the "ideal solution."

Under these circumstances, de novo programming still can be used to examine how to best design the RHS while simultaneously attaining the best possible value (less than the "ideal value") of one of the objectives. This can be accomplished by including the aggregate constraint for the log inputs plus another constraint restricting one of the objectives to its ideal value. For instance, one can minimize processing cost while setting profit at its ideal value. This formulation yields the results described as solution 1 in table 5.

Solution 1 was obtained by minimizing processing costs while setting a constraint on profits to be $319.4 million. The designed RHS under this scenario are shown in table 6. Clearly, additional dollars of budget are required in order to meet the profit constraint, even with the design of the RHS. For comparison, another de novo problem was formulated and solved. Shown as solution 2, in table 5, this problem consists of maximizing profits subject to a processing cost constraint of no more than $12.5 million. Again, even with a de novo formulation, the ideal solution is unattainable. Solution 3 in table 5 illustrates the "cost" of not designing optimal RHS's. This solution is attained by maximizing profit subject to a processing cost constraint of $12.5 million without designing the RHS's of the log availability constraints. Not only is the ideal solution infeasible, but the maximum profit, in comparison to solution 2, is reduced.

Table 5.--Comparison of solutions ($million).

Objective	Ideal solution[a]	Solution 1[b]	Solution 2[b]	Solution 3[c]
Profit	319.04	319.04	268.97	248.13
Processing cost	12.50	18.63	12.50	12.50

[a]*Infeasible.*

[b]*Obtained under a de novo formulation.*

[c]*Obtained without designing the RHS's.*

Table 6.--Optimal RHS design based on minimization of processing cost objective.

Log type	Optimal RHS design *(million ft^3)*
1	23.43
2	1.43
3	8.57
4	0
5	107.89
6	0
7	6.25
8	0
9	12.5
10	310.7
11	0
12	0
Objective	**Value**
Profit	$319.04 million
Processing cost	$18.63 million

Case IV. Designing for the System Ideal

Case II described how to optimally design the RHS, given a single objective. Case III, on the other hand, examined a multicriteria design problem where two objectives are considered. The ideal solution described in Case III consists of the optimal solution of each objective when optimized separately with a given fixed level of log inputs. In light of the results in Case II, one can think of another solution consisting of the optimal values of the objective functions which are based on optimally-designed RHS. For instance, as previously shown, the optimally-designed value for the profit objective function is \$485.23 million, while the optimal solution given fixed RHS values is \$319.04 million. The solution consisting of the optimally-designed objective function values is referred to as the "system ideal" (Zeleny 1986a). This solution is better than the ideal solution described in Case II.

Another interesting planning problem is to examine if merely designing the RHS's can make the system ideal feasible or, if not, how much would it cost to attain the system ideal. Again, this is in contrast to the traditional concept of planning which is limited to examining alternative solutions given fixed production inputs.

To determine the system ideal, it is necessary to find the optimal RHS design based on the processing cost objective. This analysis yields an optimal cost objective equal to \$12.15 million. Hence, the system ideal consists of the following values shown below.

Objective	Ideal solution	System ideal
Profit ($ million)	319.04	485.23
Processing cost ($ million)	12.50	12.15

The system ideal is also infeasible even with the designing of the RHS's. Again, this may be due to the other constraints that are treated as fixed (i.e., not to be designed) such as the demand and market restrictions imposed on the lumber products. At this point, the advantages of de novo programming over traditional models like linear programming may be further described by also designing these demand and market restrictions instead of assuming them to be fixed.

Summary

This paper has briefly introduced the subject of soft optimization using a de novo formulation of single and multiple objective LP. Following the discussion, a sample log allocation problem was analyzed using four case examples: (1) Case I: optimizing the single objective problem as given with all constraints considered hard, (2) Case II: optimizing the single objective problem as given while designing the log availability constraints subject to an aggregate budget limitation, (3) Case III: establishing the "ideal solution" where two of the objective functions are sequentially optimized with all constraints considered hard, (4) Case III: determining if the ideal solution can be made feasible by designing the RHS's of the log availability constraints, and (5) Case IV: obtaining the "system ideal" solution and determining if it can be made feasible by designing the RHS's of the log availability constraints. In both Cases III and IV, it was not possible to attain feasibility by designing the soft constraints. Thus some of the constraints considered hard must be redefined as soft if feasibility is to be achieved. However, the advantage of de novo formulation is illustrated in table 5.

The case studies illustrates the potential savings to be gained by designing optimal production levels and not simply optimizing systems as given. Clearly, to realize the benefits of such models, decisionmakers and analysts must have the flexibility to alter the RHS's of the constraints. While this is not always possible to achieve in the short run, it should be a goal to work towards in the long run.

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Multiple-Expert Knowledge Elicitation for an Intelligent Tutoring System

Daniel L. Schmoldt[1] **and William G. Bradshaw**[1]

Abstract.--Reliable extraction of human knowledge is essential for building expert systems. This may require the input of several experts. A methodology based on the Delphi technique of decision analysis is utilized for collecting and combining expertise from several different individuals. Results of this approach indicate that multiple expertise can be extracted and integrated to improve on knowledge provided by a single expert.

Development of an Intelligent Tutoring System (ITS) for wildfire prevention program planning forms a basis for the investigation of knowledge elicitation methods using several experts. A systematic approach to prevention planning has recently been developed on the San Bernardino National Forest in southern California; however, there is currently no comprehensive document for transferring the methods and rationale of the planning process to other prevention personnel. An intelligent tutor expert system is being constructed which will (1) provide instruction for learning the process and (2) assist the user in creating specific prevention programs.

Increasing urban development adjacent to wildland areas brings people activities and values at risk into closer proximity to areas of high wildfire hazard. This development introduces urban life-styles into wildlands and creates a significantly higher probability for ignitions than occurred with infrequent leisure-time use (Rice 1987). Natural resources are no longer the only values at risk; property damage and personal losses from wildfire may result from urbanization of the interface. Increased use of wildland areas (and the concomitant increase in risk) must be taken into account by those responsible for aligning wildfire prevention programs to specific wildland environments (Bradshaw and Johnson 1988). Fuels management tactics must be designed according to the wildfire threat and values at risk (Franklin 1987). Suppression activities need to accommodate the increased demand for protection and services which, because of human proximity to danger, cannot be denied (Tokle 1987). These demographic trends have created special interest groups related by similar characteristics, interests, and concerns (Rice 1987). Fire prevention programs, fuels management efforts, and fire suppression strategies must be adapted to the changing and unique fire management needs at the interface.

Wildfire prevention programs in the Forest Service, including those dealing with interface fire protection, are subject to efficiency criteria; program costs and resource losses must be minimized. Simple frequencies of ignitions are no longer the primary concern; ignitions which have the greatest potential to become large and/or damaging fires become targeted for prevention budget investment (Bradshaw and Johnson 1988). Wildfire prevention research has recently developed a comprehensive, systematic approach to prevention planning based on the efficiency criteria just mentioned.

The study reported here examines the first of several steps in developing an Intelligent Tutoring System for wildfire prevention planning. Detailed description and understanding of the prevention planning process resides only in the experiences of several prevention personnel. Therefore, it became necessary to extract this knowledge for incorporation into the ITS. Because several individuals were involved in the initial specification and composition of the planning process, inclusion of all these participants seemed desirable. Additionally, certain experts had experienced greater involvement with particular aspects of the process. Their thorough understanding, as well as the personal conceptualization possessed by each expert, was considered essential to a comprehensive representation of prevention planning.

To our knowledge, little has been proposed or accomplished in multiple-expert knowledge acquisition. Mittal and Dym (1985) and Schmoldt (1987) utilized multiple experts for initial knowledge acquisition stages. Prospective sub-problems and solution methods were intimated by protocol analysis from many experts in both reports. The former's results indicated that multiple experts are useful for identifying consistent knowledge, community knowledge, and discrete specialization. They also suggested, in the case of discrete specialization, using

[1] *Research Foresters, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, CA 92507.*

different experts within the solution of the larger problem; an approach applied by Schmoldt (1987). In addition to the above uses of multiple experts, we feel that it is important to extract in-depth, problem-solving knowledge as it resides in several individuals (community knowledge) and integrate this knowledge into a consistent representation. We are unaware of any such attempts previously.

Prior to presenting our approach to multiple-expert knowledge elicitation, prevention planning is discussed. Because the planning process defined an *a priori* framework for our tutor implementation, significant emphasis is placed on its description in the following section. We also include a brief introduction to intelligent tutoring systems.

PREVENTION PLANNING

To determine whether money spent on prevention reduces wildfire losses, prevention outputs must be balanced against goals established through systematic analysis of fire problems across entire management areas. A prevention planning process developed on the San Bernardino National Forest incorporates a detailed inventory of fire-problematic conditions. Prevention program prescriptions (locally developed and implemented) address these specific conditions; subsequent program evaluation compares fire occurrence and prescription implementation. This detailed approach provides for both accountability in program selection and follow-up assessment of success/failure.

The planning process, though systematic, still contains a large subjective aspect. Several district plans have been developed through the use of this process, but no comprehensive manual details the necessary steps and inherent rationale. To a large extent, application of the process remains a paper and pencil exercise for making and recording subjective analyses and judgments. Consequently, new users experience difficulty in beginning a fire problem analysis (the first, and essential, component of the process). The initially flat learning curve associated with this process makes it difficult for people to get the process started. The current research effort proposes that a knowledge-based tutor could facilitate learning about the planning process, and provide guidance for developing specific prevention programs.

Process Components

The planning process described here consists of the sequence of steps depicted in figure 1. Systematic analysis of fire problems constitutes the primary advantage of this planning approach. Subsequent steps rely on inventories and maps produced in the analysis phase.

Analysis of wildfire ignition problems involves the examination of three independent aspects of the wildfire situation. *Risk* analysis consists of inventorying, ranking, and mapping people activities that have the potential to cause ignitions.

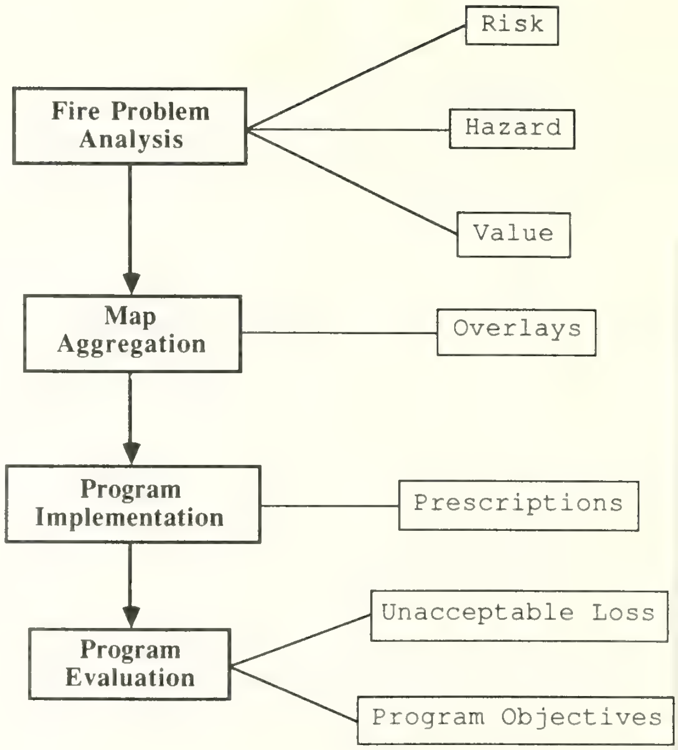

Figure 1.--The sequence of components (bold) and major sub-components contained in the prevention planning process.

Hazard analysis estimates resistance to control should a wildfire occur by evaluating wildland fuel conditions (a function of fuel type and climatic conditions) and slope classes. Ratings of resistance to control on contiguous areas are identified on a hazard map. *Value* analysis consists of inventorying, rating, and mapping potential value changes resulting from fire. Each analysis is performed independently, i.e., analysis of the potential for ignition is not affected by fire behavior analysis. Because of this independence, no particular order must be followed although each must be included in a comprehensive analysis.

After all analyses have been completed, the three maps are aggregated into one comprehensive map of the entire planning area. Currently, creation of maps remains a manual task; however, we envision for the future a utilization of geographic information systems for storage and manipulation of this spatial information. Fire prevention management compartments are delineated based upon risk analysis areas because ignition potential is the major concern of prevention. Each compartment receives a rating score for risk, hazard, and value from the analysis overlays. A final inventory summarizes and documents specific people activities, fuels, and values contained in each compartment. This aggregate map forms the data base for subsequent implementation, via program prescriptions, and follow-up evaluation.

From the combined inventory and aggregate map, specific action items are identified for each management unit. Prescriptions are written, incorporating each prevention action item; they cover duties to be performed, and their priority, under the

typical range (90th percentile) of fire conditions used in fire planning. Ninetieth percentile conditions are those fuel and weather factors where fire behavior begins to exceed the capability of initial attack forces to effect control. Contingency prescriptions may also be detailed for fire conditions that exceed the 90th percentile.

Evaluation of program effectiveness entails examinating prescriptions in relation to the extent and location of fire losses. Because the goal of prevention is a non-event (no fire), successful prevention efforts can only be assessed in terms of the numbers and severity of events that do occur, i.e., unacceptable losses. When unacceptable fire losses have not occurred, then, assuming average fire conditions, it may be possible to conclude that prevention efforts have been successful.

However, faced with losses considered unacceptable by land managers, a careful examination of those specific, damaging fire problems should identify the most prominent causes. Prevention personnel may refer to the program implementation document to verify completion of all prescribed tasks; failure to achieve specified tasks indicates a performance problem. Unacceptable losses occurring after tasks have been performed indicates that prescriptions may not be effective and need to be reconsidered. In the course of re-writing prescriptions, it may be necessary to re-analyze the risk, hazard, or value assessments associated with particular areas of losses.

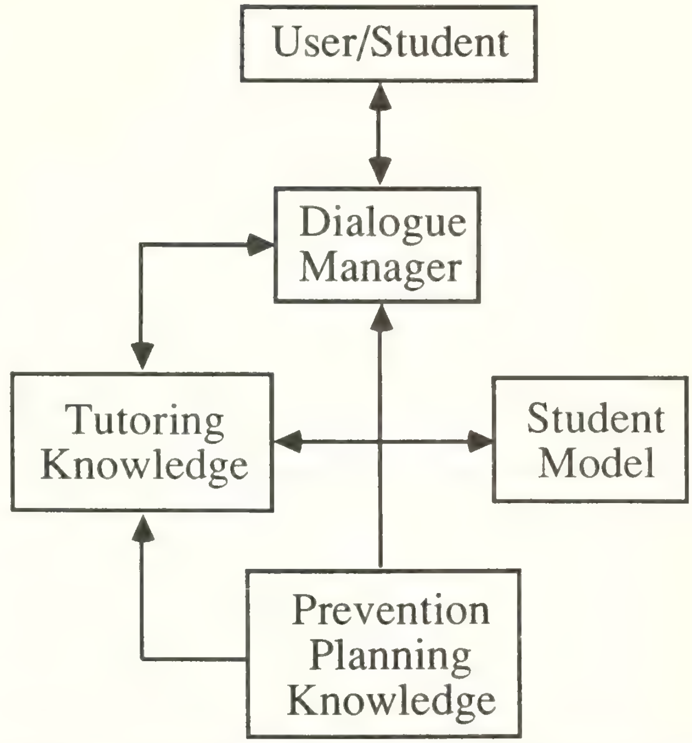

Figure 2.--Essential elements of an intelligent tutoring system for prevention planning. Arrows indicate the flow of information.

INTELLIGENT TUTORING SYSTEMS

Computer-aided instruction began in the 1950s with behavioral psychology's "linear program" view of instruction (Yazdani 1986). Under this perspective, direction toward some desired behavior is implied; reinforcing stimuli result from a successful response and direction correcting stimuli result from an incorrect response. Since this time, many other approaches have been used; most recently, knowledge-based systems have been utilized.

In addition to being effective for problem solving in forestry (Schmoldt 1987), knowledge systems possess some desirable properties for instructional uses. Expert reasoning and intuition can be represented in the system and conveyed to the student through tutored examples (example-driven problem solving) or declarative explanation (line of reasoning). The student is able to work many examples at varying complexity levels and at a comfortable pace without assistance from an instructor. MYCIN, a diagnostic expert system for infectious diseases (Davis et al. 1977), has been transformed into a tutor for medical students (Clancey and Letsinger 1981). Other tutors have been created for teaching: computer programming (Anderson and Reiser 1985, Johnson and Soloway 1985), natural language (Imlah and du Boulay 1985), geometry (Anderson et al. 1985), physics (White and Frederiksen 1986), and a pulp and paper process (Woolf et al. 1986). Merging computer-aided instruction and knowledge-based systems has resulted in intelligent tutoring systems.

Many of these ITSs have some common components; the arrangement of these components is illustrated in figure 2. Knowledge of the actual domain being taught must be captured and represented on paper or in a program, sometimes simultaneously at various levels of understanding (White and Frederiksen 1986). This knowledge is sometimes formally referred to as the "ideal student" model (Yazdani 1986). Strategies for tutoring the student in the particular domain must also be defined. These may include immediate or delayed error feedback, maintaining an actual student history (progress) model, and specifying the intensity of tutor and student interaction (dialogue management). To provide a comprehensive learning environment, the student must have access to large amounts of explanation, both for correcting erroneous behavior and promoting desired behavior. Specific implementation of these features will depend on the teaching task and types of students anticipated.

KNOWLEDGE ELICITATION

General

Our ITS approach differs from those described above by a desire to create a non-singular use system. Most ITSs contain a method of simulating or hypothesizing specific learning situations (examples) which serve as the focus of the learning environment. The prevention planning tutor being developed

operates with examples provided by individual users and presumably, reflects actual planning needs. In this way, we will create a knowledge-based system which solves actual ignition management problems and, at the same time, tutors fire prevention personnel in the techniques of the planning process.

The first step in development of the tutor involves creating a representation of knowledge about the planning process, i.e., the domain knowledge. Several prevention personnel on the San Bernardino National Forest are familiar with the process and have their own personal insights into the subtleties of fire problem analysis and program implementation. In addition, no individual within this group was previously involved in all aspects of the process to a large extent. Therefore, it became necessary to combine knowledge possessed by several experts and obtain consensus on the structure and operation of this planning process knowledge.

We selected the Delphi technique as a method for extracting and aggregating diverse perceptions of prevention planning knowledge. The Delphi technique is a general framework for arriving at agreement among individuals within a group on some particular item of interest. However, a number of serious drawbacks to this technique have been suggested previously (Shields et al. 1987): reliability of results, definition of consensus, and stability of group responses. In addition, the situation described in this paper requires the development of an extensive body of knowledge. This is an atypical use of the Delphi which is normally used to construct come scale or to estimate a point value. The authors propose a modified Delphi procedure which avoids these drawbacks and seems able to support the construction of a complex description of a planning process.

Standard implementation of the Delphi technique employs anonymous responses to questionnaires by each member of the group. Group interaction is minimized to avoid voice dominance by position or persuasiveness and to reduce the group pressure to conform (von Winterfeldt and Edwards 1986, p. 135). These questionnaires are repeatedly administered to the group, intermixed with feedback of questionnaire summaries, until some consensus has been reached. For our purposes, questionnaires would be too restrictive and inflexible for eliciting individuals' conceptual knowledge of a complex planning process. In addition, subsequent aggregation of separate expert's descriptions of highly interrelated knowledge would have been extremely difficult. A procedure which provided for progressive aggregation during the collection stage would be more efficient and require less effort. An alternative method of recording experts' opinions was sought.

The Cumulative Delphi

The following, general discussion of a modified Delphi for knowledge elicitation centers on the idea of a cumulative knowledge packet used in place of multiple copies of a questionnaire. Knowledge packets used in this study are more fully described below (see Application Specifics). Figure 3 illustrates the interaction of experts and knowledge packets in this cumulative Delphi technique. Each E_i and KP_i refers to particular experts and knowledge packets, respectively. Preliminary, general discussions are initially held with all experts to identify components of the elicited knowledge and those most experienced in each component; these individuals are given positions E_1 and E_2. For each pass of the cumulative Delphi, the most knowledgeable experts are interviewed first.

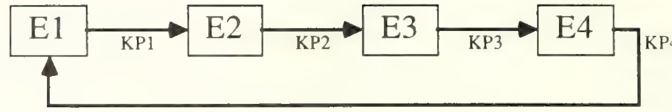

Figure 3. Routing of cumulative knowledge packets (KP1, ...) between experts (E1, ...) in the modified Delphi technique.

A pass of the cumulative Delphi is completed for each knowledge component identified previously. An interview with E_1 produces KP_1 which contains: concepts describing the particular component, definitions of these concepts, relationships between concepts, and types of concept relationships. For our needs in terms of a knowledge base, these elements seemed to capture the essential aspects of the planning process; other applications of the cumulative Delphi may require different knowledge packet contents (see Discussion). Subsequently, KP_1 is given to E_2, and E_2 is asked to make any modifications to the knowledge packet which seem appropriate. These modifications are made and recorded in an interview setting. The revised knowledge packet is then presented to E_3 as KP_2. The routing of knowledge packets continues in this manner. When KP_4 from E_4 is presented to E_1, E_1 is asked to review the changes to KP_1 contained in KP_4. If the changes are acceptable, then KP_4 is installed as the initial representation of this component of the planning process.

The case has not yet arisen in which KP_4 is unacceptable to E_1. In the event of such a conflict, two solutions are possible. Another routing of knowledge packets through the experts (beginning with KP_4 and E_1) may mitigate most significant differences, leaving only minor discrepancies whose importance will generally be small in terms of an initial representation. Alternatively, a non-confrontational arbitration may be used to smooth divergent views, in which case, the authors may mediate some mutual agreement. When the domain being represented in an expert system achieves the property of consistent expertise (a property which Buchanan and Duda (1983) considered essential to effective development of an expert system), then large deviations from consensus should not be problematic or should be easily resolved by the above procedures.

The cumulative Delphi seems to mitigate most concerns expressed previously by Shields et al. (1987). The question of reliability of Delphi results in this application relies more on the form of this domain than on the cumulative Delphi technique itself. In the planning process description, unlike consensus value assignment, a second group of experts might arrive at a different representation, but it would be functionally similar to the previous one, provided the two groups were describing the

same process. Routing of a common document forces acceptance of major points, which should be identical between two Delphi groups, and facilitates non-confrontational discussions of smaller discrepancies. Consensus is specifically defined as acceptance of the final knowledge packet by the first expert; this definition may be extended to include acceptance by all experts if it seems necessary. The commonality attribute of the knowledge packet encourages stability in progress toward a rapid consensus. Potentially valuable group interaction is sacrificed for a less engaging, but apparently effective, form of detached cooperation.

Application Specifics

The initial step of the modified Delphi, as mentioned, was a general meeting of all four experts which took the form of an unstructured interview. The investigators first presented a detailed overview of expert systems, knowledge elicitation, and the project at hand; considerable discussion took place as the experts became familiar with ITS ideas and processes. The meeting then shifted to the first discussion of domain content.

This initial phase of elicitation was facilitated by the fact that the knowledge to be developed related to a systematic planning process whose elementary logic flow was known to all (including the investigators). The initial group meeting concentrated on achieving agreement on major planning process components and definitions. Although this went well, there was evidence of rank differences between experts influencing the contribution of some members; this reinforced our plan to solicit input from the experts individually.

The meeting also enabled the investigators to gauge potential input from each expert and establish the order of involvement. Expert One was not involved in development of the process but in its subsequent application by other units of the national forest. Expert One, thus, had a good, generic over-view of the process derived from helping others with implementation, and was the perfect candidate to initiate conceptual elicitation for each planning process component. Expert Two was directly involved with specific development of the planning process. He was utilized second in our cumulative Delphi, as he was the best candidate to fill in details of each component. Expert Three was able to visualize the planning process in generic, conceptual terms. He was proficient at reviewing the knowledge packet for each component, integrating concepts and specific application details. Expert Four was less involved in development of the process but has been involved in application. He was less conceptually oriented but represented the final, user step of planning process application.

Data collection during the group meeting was the same as during individual interviews. Both investigators took notes and the dialogue was tape recorded for subsequent review.

The first private interview had the investigators engage both Experts One and Two to develop the hazard analysis component (Expert One had little to do with actual development of this component). Each expert was presented with a block diagram of the entire planning process and also a diagram for the hazard analysis. The components of the planning process were blocked out and diagrammed after the initial (group) meeting. Recall of the analysis steps was initiated by referring to documentation from earlier prevention planning and the diagram. The documentation could not be utilized directly for this study because it represented a product (a completed fire prevention plan for a specific locale) instead of the process (many of the analytical steps were hidden behind final plan conclusions). The recall itself proceeded from general points to detailed steps, sometimes re-ordering the step sequence. The tape recording of the first interview again reinforced the need to work with the experts one at a time because differences in rank occasionally influenced input.

Risk analysis elicitation illustrates the individual interview sequence. The investigators met with Expert One; he received a copy of the general block diagram developed from the group meeting. Using the diagram and copies of documentation from earlier planning cycles, he began recall of the steps of this analysis.

The input was subsequently reduced to (1) concepts and (2) relationships by the investigators through use of notes and tape-recordings. Concepts and tasks were identified from the dialogue and linked with non-directional arrows; these were verified by listening to the tape. The iterative process of working back and forth between hard copy and tape was also followed for listing definitions and relationships. As definitions for each entry on the graph solidified, relationships became readily apparent. Several general relationships were specified (fig. 4), and connecting lines became directional arrows. The risk analysis component was then graphically summarized on one page, identifying concepts, tasks, sub-components, attributes, antecedents, products, and points where documentation is collected (fig. 4). The graph, plus a glossary (fig. 4; insert) of all items in the graph, represented Knowledge Packet 1 for the risk analysis component.

Knowledge Packet 1 for risk was then presented to Expert Two. This packet provided a highly-structured interview schema for dialogue with subsequent experts. The investigators stepped through the packet item by item with the expert, clarifying anything that seemed unclear. Questions posed by Expert Two indicated aspects of graph components which needed clarification or modification. Several definitions were changed, a portion of the graph was removed, and one additional attribute was added to ignition potential activity.

Knowledge Packet 2 resulted from the changes. It was presented to Expert Three who suggested minor modifications to several definitions. Because of Expert Three's analytical abilities, he found the graphical presentation of concept and processes very natural and comprehensible. The resulting knowledge packet was presented to Expert Four who had essentially no changes to make.

The same cumulative Delphi sequence was utilized for the other components such as hazard analysis, value analysis, map

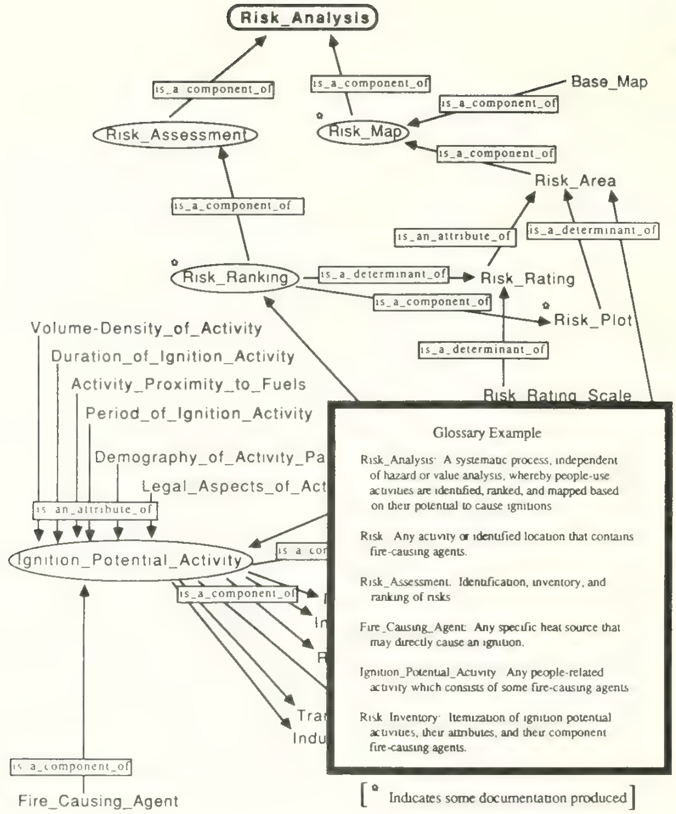

Figure 4.--Concept graph for the risk analysis component of the prevention planning process. Concepts, tasks, and their relationships (arrows) are included. A portion of the graph is obscured by the insert which contains several example definitions from the glossary for this graph.

aggregation, and program implementation. Experts Two and Four focused mainly on the terminology and definitions of the knowledge packets with less interest in the relationships. Expert Three was able to identify relationships that were incorrectly specified or should not be present at all; he used terminology definitions for purposes of understanding and correcting the concept graph. All modifications to Knowledge Packet 1 that occurred in the routing process have been of two types: (1) changes resulting from misconceptions on the part of the investigators, or (2) minor changes to definitions or graph relationships. Neither of these represented significant modifications to the original knowledge packet from Expert One.

DISCUSSION

Products of our knowledge elicitation efforts appear sufficiently comprehensive for actual construction of the tutor (in which we are currently engaged). In terms of the concept graph, all components, their dependencies, and their relationships have been enumerated. A textual description of this information also resides in the attached glossary. In addition, we have tape-recordings of all discussions which may contain minor points and examples not captured by the knowledge packets. The task that remains is representation of that knowledge in a form that permits learning the process and formulating actual prevention programs.

On the basis of preliminary work with knowledge elicitation in this study, a number of interesting observations can be made. Due to the previously unrecorded nature of prevention planning process knowledge, our efforts to date have identified and scrutinized what is known about the planning process, and have contributed significantly to its understanding and formalization. Specific planning process tasks and fire prevention concepts have been isolated and their meanings solidified. There were subtle, yet significant, aspects of the process which previously had not been realized by one of us (Bradshaw) who was very familiar with the planning process. Areas of subjective knowledge used by the experts at various steps in planning have been identified; this judgmental component will be formalized in subsequent stages of this project. Even should a tutoring system not be developed from this study, advances in understanding and formalizing the process make the elicitation task itself quite worthwhile.

The sequenced elicitation approach used here uncovered some areas of the planning process where guidance could be useful in making judgments, especially in quantifying previously subjective judgments. The experts agreed on benefits of

such an approach, but related difficulties they experienced when trying to quantify judgments. Interestingly, the difficulties seemed to arise from a desire to "count" instances of a sub-component (e.g., the number of dwellings in a prevention compartment) rather than numerically rate attributes of the sub-components in the compartment (e.g., volume-density of dwellings, duration of associated ignition activity, period of activity, demography of participants). The change to be incorporated in the tutor is to guide attribute ratings for sub-components instead of dealing solely with counts or frequencies.

Even though other types of knowledge have not been addressed in this study, the general cumulative Delphi approach could be universally applied. Knowledge in this application consists of tasks and concepts, a dependency list of items to accomplish and/or ideas to comprehend. The form and details of the knowledge packets reflect this usage. If an investigator were eliciting decision rules (inferences) from experts, different knowledge packets would be necessary. In such an instance, packets might contain actual rules elicited and their justifications, or they could be responses/solutions to real-world examples, which could subsequently be used to construct inference rules. Irrespective of the type of knowledge, content of the packet should be as equally detailed as the level of knowledge required in the system being developed.

In addition to the type of knowledge and level of detail, several other aspects of knowledge packets should be addressed. Some consideration should be given to experts' capabilities to understand the format of the packet. As we discovered in our experiences, not all individuals were equally comfortable with the format of our knowledge packets. Expert Three seemed very comfortable with, and readily grasped, the concept graph presentation; Expert Four was less analytically inclined. Also, decomposition of the entire problem space into smaller problems means that less information needs to be included in a single packet. This is an axiom of knowledge system development and has been reinforced by our experiences and so deserves mention here. Complexity will be reduced, and a single packet will be less likely to overwhelm an expert. In addition, it may be useful to have two tape recorders present during interviews. One would be used for current recording, and the other for replaying specific comments by other experts. This is valuable during points of dissension in which investigators are unable to recall exact details of a previously interviewed expert's arguments. Preliminary group or individual interviews can provide guidance for making these decisions.

Although using multiple experts makes the knowledge elicitation bottleneck of expert system development more pronounced, each expert has some personal intuition and perspective which has proven valuable to the overall knowledge collected. Cumulative Delphi methods have facilitated the capture and aggregation of these diverse opinions. On several occasions, an expert has discussed particular details which would not have been proffered in a group situation. Individuality seems to have been preserved while realizing group consensus. It appears that the knowledge packet approach, especially when walking each expert through a packet, provides sufficient interaction of ideas without disruptive confrontation or dominant role playing. Later, experts required very little time to review each packet because of the level of completeness already achieved. Any additional time consumed for multiple experts would otherwise have likely been spent in revising material, re-interviewing a single expert, and possibly restarting the elicitation process. The visual aid quality of the knowledge packet also helps application-oriented people (experts) make the transition from work-related experience to verbalizing abstract concepts.

For expert system development where several experts are available, it seems prudent to exploit their separate, private knowledge. A methodology has been outlined which induces such elicitation and facilitates its consentaneous synthesis.

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Nonlinear Learning Curves and Forest Management Planning

Dennis P. Dykstra[1]

Abstract.--Learning curves have been used since the 1930's to account for long-cycle learning in production processes. They have seldom been used in forestry because the traditional learning-curve model fails to account for variables other than the cumulative number of units produced. This paper reviews the theory of learning curves and suggests a new learning-curve model suitable for complex forest operations in which long-cycle learning may be important.

Good estimates of production rates for forest operations are essential for accurate forest management planning. Traditionally such estimates have been made by developing regression equations from studies of existing operations and then using those equations to estimate production rates for planned operations in areas of similar timber and terrain conditions. One important shortcoming of this method is that it fails to account for long-cycle learning and forgetting effects that can significantly influence production rates of operations such as logging, which can be affected by training or by seasonal changes such as heavy rains or snowfall. Learning effects can be particularly important in developing countries, where policy decisions may include consideration of whether to adopt new technology or to emphasize more traditional methods.

Learning Curves

It has been demonstrated for a wide variety of production processes that, as an individual worker or crew continually repeats the process, productivity shows gradual and predictable improvement (Yelle 1979). For instance, when a person begins planting trees for the first time, that individual is likely to proceed slowly at first, working carefully but making many unnecessary and time-consuming movements. After a few days or even hours, the worker becomes more comfortable with the process and settles into a faster and more efficient working pace.

Learning-curve theory postulates that the time required to produce a fixed quantity of output (e.g., the time required to plant 1,000 seedlings) will be reduced for quite some time at a more or less continuous rate, until eventually a "working plateau" is reached, beyond which essentially no further improvement can be expected without additional investment such as training in improved methods or the purchase of new planting equipment. This general concept is illustrated in figure 1. Note that a fixed *rate* of reduction in the time to produce one unit (e.g., a reduction of 0.1% per seedling in the time required to plant a seedling) corresponds to the familiar negative exponential or "reverse J-shaped" curve.

From observations on improvements in production processes, Wright (1936) hypothesized that the rate of improvement for a particular production process could be measured and used reliably to predict future production rates. Wright's model assumed that improvements during the learning phase would proceed at a constant rate. Repeated tests of the model since that time have confirmed that this assumption is satisfactory under a wide variety of operating conditions (Yelle 1979). Wright's model can be stated as follows:[2]

$$Y_N = \alpha N^{\beta} \qquad [1]$$

where

Y_N = the time required by a worker or crew to produce the Nth unit in a series (e.g., to plant the Nth seedling);

α = an estimate of the time required to produce the first unit in the series (thus, α is an estimator of Y_1);

β = a constant that measures the rate at which the time required to produce a single unit changes relative to the cumulative number of units produced.

[1]*Professor, School of Forestry, Northern Arizona University, Flagstaff, AZ 86011.*

[2]*Wright's original model was based on the cumulative average time (i.e., the total time required to produce the first N items, divided by N). Later Crawford (1944) suggested that the unit model specified in equation [1] would be more reasonable for certain types of production processes. This latter model seems generally more applicable to forest operations than Wright's cumulative-average model.*

In this "log-linear" model of productivity improvement, the parameter β is often referred to as the "learning index." If $\beta < 0$ then productivity is improving; if $\beta = 0$ then productivity is constant; and if $\beta > 0$ then it is worsening.

Another quantity commonly used to characterize learning curves is the "progress rate" (called the "learning rate" by many authors), calculated as $\sigma = 2^{\beta}$, where σ is the expected time required to produce unit $2N$, expressed as a fraction of the expected time to produce unit N. A learning curve with $\sigma = 0.8$ is often referred to as an "80% curve." Lower values of σ imply faster rates of productivity improvement. In my experience, having taught the concept of learning curves to university students in both North America and Africa, I have found that this is the opposite of what many people assume when they hear the term "learning rate." Therefore, although σ is defined as the learning rate by many authors, I prefer to call it the progress rate, and to define the learning rate as $\delta = 1 - \sigma$. In this definition, a higher learning rate implies faster improvement in productivity, which is consistent with popular usage if not with standard usage in the terminology of learning-curve theory.

Learning Curves and Forest Operations

The fact that productivity improves over time in forest operations has long been recognized intuitively by operations managers, but there have been few attempts to measure this improvement or incorporate it into operations planning. The most common approach in productivity studies of forest operations has been to assume that the process under study has already reached the working-plateau phase, so that no adjustment for improvements in productivity over time is necessary. If this assumption is correct, then there is no difficulty; but if the assumption is wrong, then productivity will be underestimated and appraisals (for instance, to determine stumpage prices) will overestimate production costs.

Although the learning-curve concept has not been widely used in research on forest operations, several studies are worthy of mention. As a result of experience with machine felling in eastern Canada, McNally (1977) developed a simple procedure to take into account the effect of on-the-job training on productivity. McNally's conjecture was that a new machine operator would require about 6 months to achieve the productivity of an experienced operator. During the training period, productivity could be expected to increase steadily (i.e., at approximately a constant rate), beginning with a production rate about one-third that of an experienced operator.

Around the same time, Garland (1979) initiated work designed to measure improvements in productivity associated with the training of chokersetters. Garland's primary interest was in the tradeoffs among the training investment, frequency of job changes (i.e., job satisfaction), and increased productivity. In the course of this and later work (Garland 1981), he measured learning curves for several crews of chokersetters, reporting average learning rates of around 10%. This means that the expected time required for a crew to accomplish the chokersetting task for the 200th turn of logs would be about 10% less than the time required by the same crew to accomplish the same task for the 100th turn of logs, all else equal. Garland's work also suggested that for the crews in his studies, a working plateau would be achieved for which chokersetting times would average approximately 56% of the time required to set chokers on the first turn of logs.

A recent study by Greene and others (1987) found that felling-machine operators using an interactive simulation model as a training device "learned" at rates significantly below those reported by Garland. The learning rate for the operator who improved the most during the study was 3.3%. Reduced learning rates (i.e., nearer to 0%) are to be expected in mechanized operations where machine-pacing largely determines the rate of production; hence the much more rapid rate of productivity improvement in Garland's chokersetting studies.

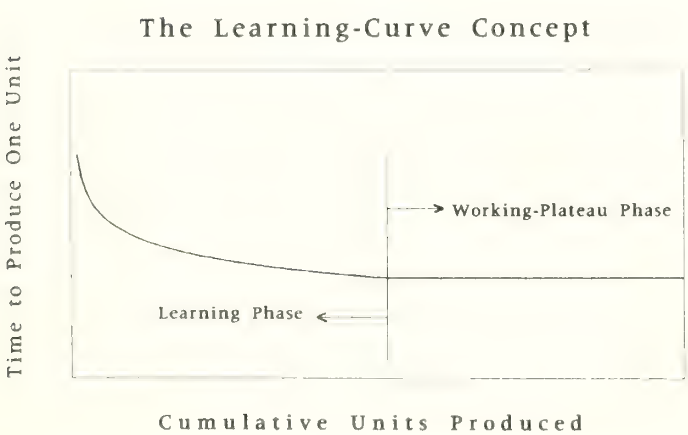

Figure 1.--The learning-curve concept, showing the "learning phase", during which the time to produce a fixed quantity of output is gradually and continually reduced, and the "working plateau phase," during which average output per unit time is essentially constant.

Learning Curves Under Variable Conditions

Learning-curve theory was originally developed for "long-cycle" factory operations, and has been most commonly used in that type of production environment. Long-cycle operations are those that require significant time to complete, such as the construction of an airplane. Most forest operations would also be classified as long-cycle operations, as opposed to short-cycle operations such as pulling lumber off a conveyor chain, where each operation requires only a few seconds.

In the controlled environment of a factory, conditions remain relatively constant from day to day, so it seems sensible that the primary variable considered to influence production

rates is the number of long cycles that have been completed during a production run (e.g., the number of airplanes produced). Conditions associated with forest operations, on the other hand, are highly variable. Although the total number of tree seedlings planted by an individual may influence the time required by that individual to plant the next seedling, many other factors can influence that time as well. A few examples include slope steepness, soil type, the amount and character of ground cover, weather conditions, and the payment system (e.g., hourly wage versus a piece rate). Forest operations, in this sense, can be thought of as "more complex" than factory operations. Because learning-curve theory fails to account for variables other than the cumulative number of units produced, learning curves have seldom been used in forest productivity studies.

A New Learning-Curve Model

To account for the many variables that influence productivity in forest operations and yet simultaneously consider the effect of cumulative production on productivity, it seems reasonable to propose the following learning-curve model:

$$Y = \alpha_0 + \alpha_1 X_1 N^{\beta 1} + \alpha_2 X_2 N^{\beta 2} + \ldots + \alpha_m X_m N^{\beta m} + \alpha_{m+1} N^{\beta m+1} \qquad [2]$$

where

- Y = the dependent variable to be estimated (e.g, the time required to fell the *N*th tree),
- α_j = a regression parameter ($j = 0, 1, ..., m+1$) measuring the contribution of variable X_j to variable Y,
- X_j = an independent variable (e.g., dbh of the *N*th tree),
- N = the cumulative number of units produced (e.g., the number of trees felled),
- β_j = a regression parameter ($j = 0, 1, ..., m+1$) measuring the rate at which the contribution of variable X_j to variable Y changes in proportion to the cumulative number of units produced.

Except for the nonlinear terms $N^{\beta j}$ and the m+1 term, equation [2] looks exactly like the typical regression model used to estimate the time required for an individual forest operation, such as tree felling. Parameter α_0 accounts for any fixed times in the production of a single unit, and the α_j ($j = 1, 2, ..., m$) measure the individual contributions of the independent variables to the overall estimated time for the operation. The final term in the model looks exactly like the traditional learning curve in equation [1]. This model is thus a hybrid of the traditional learning-curve model and the traditional operations-productivity model. It permits explicit estimation of two types of learning:

(a) overall learning associated with the entire operation (the m+1 term);

(b) learning associated with each independent variable (the $N^{\beta j}$ terms).

An Empirical Test

In 1982 a research project undertaken by Migunga (1982) and reported in Migunga and Dykstra (1983) provided an unusual opportunity to measure learning rates for chainsaw felling in Tanzania. Migunga's research was designed to compare the cost of cutting plantation timber with crosscut saws versus the cost of using chainsaws. The chainsaw component of the study offered a good chance to test learning curve theory because the workers involved in the study had no previous experience with chainsaws (although they were experienced in the use of crosscut saws).

The study was conducted in a plantation of *Pinus radiata* D. Don at the Training Forest of the University of Dar es Salaam near Arusha in northern Tanzania. The trees were 16 years old and were being clearfelled because of damage by the fungus *Dothistroma pinii*. Before initiating the study, the workers were given a week's training in safety, operation, and maintenance of the chainsaws. Then a detailed time study was commenced in which every aspect of the cutting operation was timed with stopwatches.

Like many production studies of forest operations, the cutting study was divided into work elements (felling, limbing, measuring, and bucking). For each element the productive time and any delay time were recorded to the nearest 0.01 minute. Data on independent variables expected to influence production rates were also measured and recorded. These included, for each tree, the diameter at breast height (dbh) in centimeters, total tree height (H) in meters, number of logs cut from the stem (NLogs), and the volume of each log (V) in cubic meters. The 221 trees involved in the chainsaw study averaged 31.6 cm (12.4 in) in dbh with an average total height of 26.2 m (86 ft) and an average total merchantable volume over bark of 1.05 m^3 (about 160 board feet). The volume harvested from the compartment averaged 172 m^3/ha (about 10.5 mbf/ac).

Traditional Regression Analysis.--Figure 2 shows a time series of productive (i.e., delay-free) felling times for the 221 trees involved in the chainsaw study (in this paper, the term "felling" is used to refer to the entire cutting operation, including felling, limbing, measuring, and bucking). Although there appears to be a slight downward trend toward the right side of the figure, there is so much variability about this trend that any simple characterization seems unlikely to be useful. The approach used by Migunga to analyze the data was that of the traditional operations-productivity model, which assumes that the crew has already reached the "working plateau" phase (i.e., learning no longer occurs). The dependent variable was productive felling time in minutes per tree. Independent variables tested for inclusion in the regression model were dbh, dbh^2 (a surrogate for basal area), H, NLogs, and V. Variables accepted

for inclusion had to be statistically different from zero with a maximum error probability equal to 0.05. Migunga's final model, selected using ordinary least squares, was as follows (numbers in brackets below the regression coefficients are the standard errors of the respective coefficients):

$$\underset{[2.913]}{T = 8.589} - \underset{[0.185]}{(0.450)(dbh)} + \underset{[0.0027]}{(0.0141)(dbh^2)} + \underset{[0.351]}{(0.897)(NLogs)} \qquad [3]$$

$R^2 = 0.64$, overall $F = 131.3$, $n = 221$

Traditional Learning-Curve Analysis.--Although Migunga's analysis would ordinarily be considered quite satisfactory, because of the fact that the study involved workers with no prior experience in chainsaw felling, it seemed reasonably certain that some improvement in skill levels ("learning") *had* taken place during the study. If true, this would imply that one of Migunga's basic assumptions, that the working plateau had been reached prior to the beginning of the study, was violated. We therefore decided to see whether the traditional learning-curve model would explain any of the variance in the data. To do this we used the logarithmic transformation of equation [1] to fit the traditional learning curve as follows:

$$\log(T) = \underset{[0.129]}{3.375} - \underset{[0.029]}{(0.199)(\log(N))} \qquad [4]$$

$R^2 = 0.18$, overall $F = 48.6$, $n = 221$

Both of the parameter estimates in equation [4] are significant with error probabilities less than 0.001. Assuming the parameters are free of bias, the log-linear equation can be written in a form equivalent to that of equation [1]:

$$T = (29.228)(N^{-0.199}) \qquad [5]$$

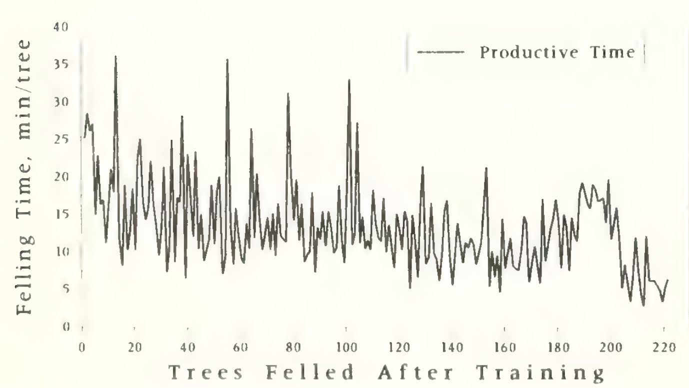

Figure 2.--Time series showing the productive felling time (the total of felling, limbing, measuring, and bucking times but not including delay times), in minutes per tree, for the 221 trees involved in the chainsaw-felling study of Migunga and Dykstra (1983).

From the definition of the learning rate, δ, it follows that

$$\delta = 1 - 2^{-0.199} = 0.13 \qquad [6]$$

In reflecting on the results of this traditional learning-curve analysis, we concluded (Dykstra and Migunga 1986) that equations [4-6] were of little practical use. The analysis assumes that the only variable exerting an influence on cutting productivity is the cumulative number of trees felled; independent variables such as dbh and NLogs are assumed to have no effect. If such independent variables actually do influence cutting time per tree (and equation [3] suggests rather strongly that they do), then the traditional learning-curve analysis of equations [4-6] would only be useful if the magnitudes of the independent variables were *constant* for all trees felled, *both during the study and on future operations for which production rates are to be estimated by the equations*. But if that were the case, then equation [3] could not have been estimated at all. Clearly, then, the traditional learning-curve approach is too restrictive for application in this type of logging productivity study. Furthermore, it is evident from this discussion that equations [4]-[6] may either overestimate or underestimate the learning effect, depending upon whether trees felled later in the study were larger or smaller than those felled earlier in the study.

Modified Learning-Curve Analysis.--Although Migunga and I initially formulated the model of equation [2] in 1982, for several years we were unable to test it numerically because the only computer to which we had access was a Hewlett-Packard[3] Model 85 microcomputer with 32 Kbytes of main memory, programmable only in BASIC. A major difficulty with the model of equation [2] is that it is intrinsically nonlinear; there is no way to transform it into a linear approximation (as can be done with the log-linear model of equation [1]). The HP-85 microcomputer was capable of calculating the linear regressions of equations [3] and [4] for 221 observations, but we were unable to program it to run a nonlinear regression analysis for the model of equation [2] because the memory requirements, even for a small subsample of the 221 observations, far exceeded the machine's capacity of 32 Kbytes.

Recently I acquired an IBM PC/AT[3] microcomputer with 1 Mbyte of main memory and an 80287 numeric coprocessor. Using this computer with the nonlinear least-squares option of the Micro-TSP[3] software package (Hall and Lilien 1987), I was able to fit the model of equation [2] to the 221 data points from Migunga's felling study. The result was the following regression equation. Convergence was achieved by Micro TSP after 13 iterations and required approximately 83 seconds on the IBM PC/AT.

$$T = \underset{[0.0688]}{(0.4389)(dbh)}\ \underset{[0.0749]}{(N^{-0.2231})} + \underset{[0.00105]}{(0.00452)(dbh^2)} + \underset{[0.3040]}{(0.7156)(NLogs)} \qquad [7]$$

$R^2 = 0.71$, overall $F = 174.7$, $n = 221$

[3] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by Northern Arizona University or the U.S. Department of Agriculture to the exclusion of others that may be suitable.

The four parameter estimates are all significantly different from zero with maximum error probabilities of 0.02. Comparing the model of equation [2] with the fitted results in equation [7], note the following:

1. the constant term was not significantly different from zero and has been dropped;
2. the overall learning effect (term m+1 in equation [2]) was not significantly different from zero and has been dropped;
3. the only significant learning effect corresponding to the independent variables was that associated with dbh. This suggests that the cutters' skill improved over time in proportion to the number of trees cut, but only with respect to the variability in cutting times explained by dbh.

Figure 3 provides a comparison of cutting times estimated with equation [7] to the observed cutting times for the study (the "envelope of observations" has been drawn by joining peaks from the time series in fig. 2). Much of the variability in the original time series has clearly been captured by equation [7], as has the general downward trend in the data.

Figure 4 compares the traditional learning curve of equation [5] with that of equation [7] plotted for the average values of dbh (31.6 cm) and NLogs (4.2) encountered during the study. It is apparent from the chart that the traditional learning curve overestimates the learning effect (i.e., the traditional curve is steeper than the nonlinear learning curve). From a cursory look at equations [5] and [7], this result may at first seem surprising. The learning index of equation [5] is -0.199, corresponding to a learning rate of 13%, whereas the learning index of equation [7] is -0.223, corresponding to a learning rate of 14%. Why, then, is the traditional learning curve the steeper of the two? The answer is that the learning rate of equation [7] is associated only with dbh and not with the entire equation. Therefore, the improvement in skills measured by equation [7] corresponds only to the contribution of dbh to the explanation of variance in the dependent variable. An inspection of the time-series data for Migunga's study shows that some of the apparent "learning" measured by the traditional learning curve is due to the fact that the average dbh of trees felled during the study declined slightly as the study progressed. Because the more flexible model of equation [7] considers the effect of independent variables as well as that of the learning trend, it is more likely to avoid such spurious correlation effects.

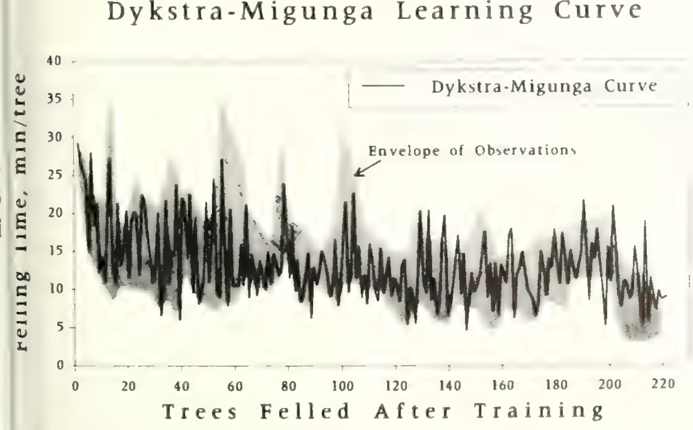

Figure 3.–Comparison of the actual time series of observations ("envelope of observations") to cutting times estimated with the nonlinear learning-curve equation.

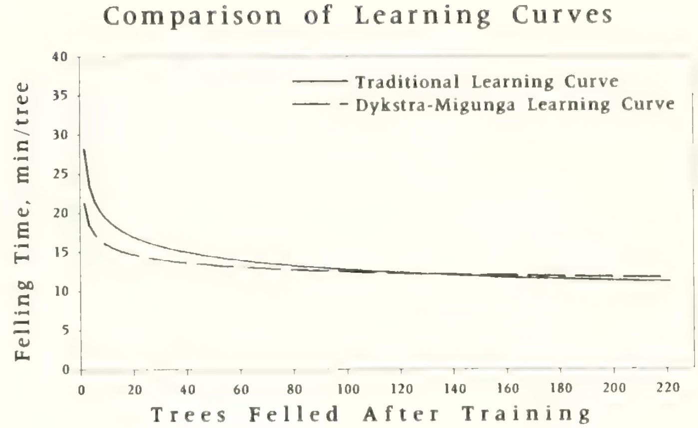

Figure 4.--Comparison of the traditional learning curve for the felling time study with the nonlinear learning curve fitted to the Dykstra-Migunga model and plotted with the average values of the independent variables measured during the study. The traditional learning curve overestimates learning because by chance the trees cut later in the study were somewhat smaller than those cut earlier.

Concluding Remarks

The nonlinear learning-curve model proposed in this paper as a basis for measuring improvements in skills over time shows considerable promise for applications in long-term planning and control of forest operations. As a hybrid model combining elements of the traditional learning curve with the regression model traditionally used in studies of forest operations, it permits learning rates to be measured while also permitting measurement of the contributions of independent variables to production rates and costs. The primary disadvantage of the nonlinear learning-curve model is that it is intrinsically nonlinear in form, and therefore requires access to a computer and software capable of fitting nonlinear regression equations.

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An Application of FORPLAN for Regional Timber Projections

Charles H. Strauss and Roger G. Lord[1]

Abstract.--Timber availability was forecast over a 100-year period for one of Pennsylvania's more valuable hardwood regions using the USDA Forest Service FORPLAN model. The eight-county region was found to have a sawtimber production capability that could more than triple during the next 60 years. Age class distributions would also become more balanced, thereby tempering cyclical harvest patterns.

Timber resources are gaining increased attention within northeastern United States. In part, this relates to the gradual transition of these intermediate aged hardwood forests to a more mature and marketable status. Allied with this change has been a moderate increase in the output of forest products and in the export of logs and lumber to foreign markets. The renewed interest in timber may also be attributed to a general search for alternate means of revitalizing Northeastern economies. Whether these forests can serve as a catalyst to development will depend on the long term production capability of the forests and the economic advantage available to resident industries.

In Pennsylvania, forests extend over 16.8 million acres, representing 58%of the state. While Pennsylvania ranks only 33rd in land area among all states, it is 12th in total timberland (forestland producing or capable of producing crops of industrial wood of more than 20 ft^3/ac/yr, and not withdrawn from timber utilization). This includes 20 billion cubic feet (bcf) of hardwood growing stock; more than any other state in the country. About 50% is in sawtimber stands, representing 42 billion board feet (bbf) of hardwood sawtimber (Powell and Considine 1982). The size and stature of this resource base is also reflected in lumber production, with Pennsylvania ranked first among all states in hardwood lumber output during 1986 (National Forest Products Association 1987).

The State's present forest developed with only a minimum degree of forest management. Prior to 1880, timber harvesting was largely directed toward the more accessible pine and hemlock stands. Major clearcutting followed during the period 1880 to 1900, in tandem with the development and use of railroads for logging and hauling. By 1920, the remaining virgin and partially cut softwood stands had been clearcut (Marquis 1975). Much of this forest gradually regenerated to hardwood types, with the primary management effort directed to fire protection. Now, large portions of the forest are reaching harvestable age.

The impending maturation of a large proportion of the state's timberland has led to some speculation that the timber production upswing experienced in Pennsylvania at the turn of the century could be repeated. However, neither the short term nor the long term productive capability of the major timbersheds have been quantified. The dynamics of forest development and management need to be explored in terms of their impact on future timber yields and forest structure.

A series of studies was initiated by Penn State's School of Forest Resources to evaluate the timber availability within one of the State's key forest regions and to assess the current structure of the region's forest products industry. Two timber production models were developed to determine the potential long term flow of timber products from the region's public and private ownerships. This paper describes the design and results of the second regional model.

Description of the Study Region

The Allegheny Region, an eight-county area located along the northern tier of Pennsylvania (fig. 1), was selected for study because it comprises one of the State's more valuable timbersheds. The region is 84% forested and contains the largest per acre and total growing stock volumes of any of the eight forest survey units in the state (Powell and Considine 1982). It also includes over 20% of the state's timberland, about 3 million acres. The more valuable northern hardwood types dominate, representing 69% of the timberland. Upland oak types are found along the southern portion of the region and comprise 21% of the timberland area. Nearly 55% of the acreage was classified as

[1]*Associate Professor, Forest Economics; Staff Forester, Texas Forest Service, College Station, Texas 77843.*

sawtimber stands, with 37% in poletimber and 7% in seedling/sapling (Considine and Powell 1980).

Timberland within the region is actively managed by both the public and private sectors. Forty-two percent of the timberland was under public management, organized by the U.S. Forest Service, the Pennsylvania Bureau of Forestry, and the Pennsylvania Game Commission. Over 17% of the timberland was managed by the forest products industry and an additional 10% was owned by nonforest-based industries. The remaining 31% was owned by farmers and other private non-industrial classes (Considine and Powell 1980). Over 60% of the private timberland was situated on tracts exceeding 200 acres in size, with 45% in tracts over 1,000 acres. An active forest management attitude was prevalent within these properties, with 72% of the private timberland controlled by owners who had harvested in the past (Birch and Dennis 1980). Owners who had not harvested in the past most often cited immature timber as their primary constraint.

A sizeable forest products industry was identified within the Allegheny Region (Westman et al. 1985). In 1981, there were 480 forest product processors within the region, comprised of 356 logging contractors, 89 primary manufacturers, and 33 secondary manufacturers. Sawmill consumption of logs was estimated at 160 million board feet (mmbf), Doyle scale, per year. The value of shipments from the forest products industry in that year was $366 million. Nearly 4,000 full-time equivalent workers were employed by this industry; representing 15% of the total employment within the region's manufacturing industries.

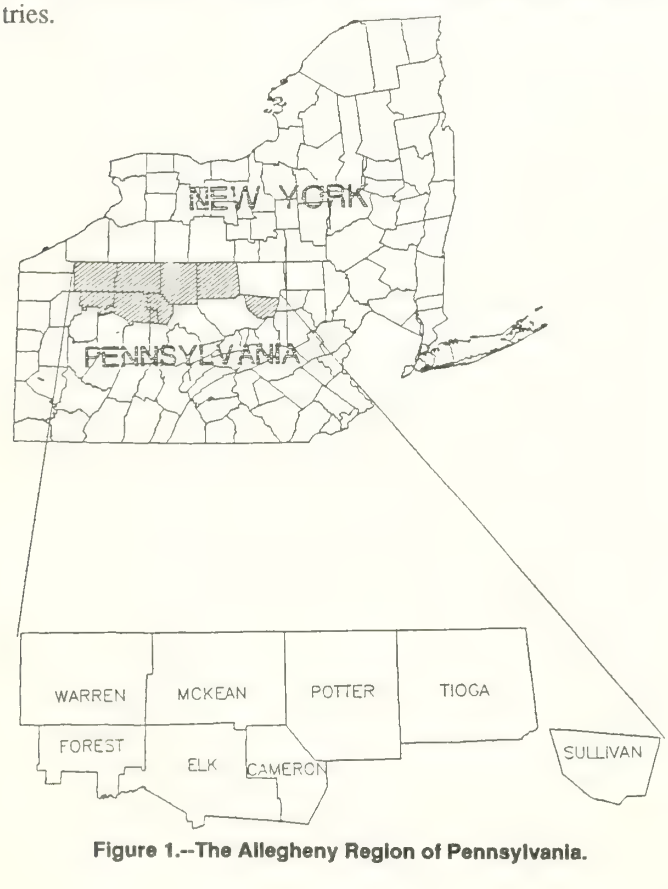

Figure 1.--The Allegheny Region of Pennsylvania.

An initial study of sawtimber availability in the Allegheny Region by Strauss and McWilliams (1987) provided a starting point for timber assessments. The TRAS stand projection model (Larson and Goforth 1974) was used for estimating sawtimber availability over a three decade period, 1980 to 2010. Stand size distributions were modified within the TRAS model by including the forest management strategies of the region's public and private ownerships as an integral component of the model (McWilliams 1985). Model forecasts indicated a potential doubling of sawtimber harvests, to an average annual level of 425 mmbf (International 1/4") in the 1990's. However, in the following decade, the projected output fell to an average annual level of 318 mmbf. A continued imbalance of age classes was identified as a further cause for larger reductions in sawtimber output by the middle of the next century. The restricted planning horizon available to the TRAS-based model, in combination with the forecast of a potential decline in the region's production capability, were sufficient causes for developing an expanded timber projection model.

Model Selection and Development

An improved timber projection system was developed for the region using the USDA Forest Service FORPLAN model (Lord 1985). The linear programming structure of FORPLAN, compared with the TRAS model, permitted an expanded view of the region in terms of a longer projection horizon and a complete set of timber outputs. The FORPLAN model also provided a more explicit model of the dynamics of forest structure in terms of growth, inventory, and age class distribution. In addition, the forest management strategies employed by the various ownership groups could be more precisely represented in the model.

Although linear programming models in forestry have been largely directed toward optimizing management activities under somewhat singular ownership objectives, an alternative application has been proposed by Alig et al. (1984) involving the broader context of simulation. Within this perspective, a forest optimization model, rather than seeking a normative course of action, could be used to predict future outcomes based on a set of pre-defined assumptions concerning timberland management. These management strategies would be represented mathematically within the LP formulation.

The approach taken in this study simulated future timber yields from the multi-ownership Allegheny Region. General forest management strategies of the various ownership groups were identified and translated into an objective function, constraints, and silvicultural prescriptions of the FORPLAN model. Access to FORPLAN version II was made available to the Penn State School of Forest Resources by the USDA Forest Service through the Allegheny National Forest headquarters at Warren, Pennsylvania.

The general FORPLAN model is organized from several basic components: an objective function, planning horizon,

analysis areas, prescriptions, yields, activity variables, and constraints (Johnson et al. 1983). The objective function for the regional model was directed to maximizing the non-discounted harvest of sawtimber, in million cubic feet, over a 100-year planning horizon. The planning horizon was divided into 10 decades beginning in 1980 and ending in 2079. A volumetric objective was chosen over a financial objective to better represent the cumulative actions resulting from a complex of ownership decisions. These decisions are not always based on financial criteria, particularly within the public sector where volumetric measures are consistent with certain management strategies in practice; e.g., area control and nondeclining even flow. Nor can this complex of decisions be traced to any given point in time, as would be implied by a discounted cash flow analysis.

A sawtimber measure was initially used in the objective function, rather than a combined sawtimber and pulpwood measure, to reflect the primary objective of most hardwood management strategies. In part, this referenced to the traditional financial strength of sawtimber markets and the continued weakness of pulpwood prices within the region.

Acreage allocated to timber production was determined exogenously to the FORPLAN model. Implicit to the model was the assumption that the amount of timberland would remain constant over the planning horizon. The loss of timberland in this largely rural region has been minimal during the past two decades (under .1% annual) and no major land use changes are expected within the next three decades (Powell and Considine 1982).

The region's timberland was stratified among 75 potential analysis areas based on five ownership groups, three broad forest types, and five age classes. Conceptually, an analysis area represents a distinct homogeneous resource unit available to management by its owners. Ownership groups included the USDA Forest Service, the Pennsylvania Bureau of Forestry, the Pennsylvania Game Commission, private ownerships with properties over 200 acres in size, and private ownerships with properties under this size. The subdivision of private ownerships by tract size was an effort to recognize larger property ownerships having a better potential for long term management and greater likelihood of more intensive management. The forest type stratifications included the oak types, the northern hardwood types, and the allegheny hardwood type. The latter is a variant of the northern hardwoods and includes stands that typically have larger volumes and values due to higher percentages of black cherry *(Prunus serotina)*, ash (*Fraxinus* sp.), and yellow poplar *(Liriodendron tulipifera)*.

Because of a lack of more detailed age data, stand age classes were derived from stand size class information. Stand age classes were 1-30 years, 31-50 years, 51-70 years, 71-90 years, and 91 years or older and corresponded to respective stand size classes of seedling/sapling, poletimber, small sawtimber, large sawtimber, and large sawtimber exceeding a 90-year rotation age (USDA Forest Service definitions). The age assignments were derived from stand size correlations found within the 1978 Pennsylvania forest survey data (McWilliams 1985). Unfortunately, site quality information was not available in a consistent form for all ownerships and could not be used as a basis for additional stratification of the timberland base. The forest type and age class distributions within any ownership group were developed from inventory information maintained by the public agencies and, in the case of private ownership, from the USDA Forest Service plot data acquired during the 1978 forest survey of Pennsylvania.

Silvicultural prescriptions, represented in the regional FORPLAN model as a sequence of harvesting activities, described the alternative management activities that could be implemented. Timing options for each prescription described the range of ages or periods in which the treatments could be implemented; e.g., rotation or thinning ages. For each analysis area, FORPLAN generated all possible unique prescription-timing option combinations. These prescription-timing options became the linear programming decision variables, and one column was generated for each in the LP matrix. A total of 1,061 prescription-timing options were defined; an average of 16 options per analysis area.

The selection of alternative silvicultural prescriptions for the regional model was based on a previous survey of ownership groups in the Allegheny Region by Strauss and McWilliams (1987). Although this survey found certain differences in management strategies among the ownership groups, their basic prescriptions were consistent with the silvicultural guidelines developed by the USDA Forest Service for northern hardwood forests (Marquis et al. 1984).

Four prescriptions were defined, represented by three combinations of intermediate and rotation harvests for even-aged management and a selection management system for uneven-aged management. The even-aged silvicultural prescriptions were generally organized toward a rotation length of 85 to 115 years. During the rotation interval, the stands received a series of zero to two thinnings to promote growth and quality within the residual stand. Longer rotations, up to 155 years, were allowed on the analysis areas of the USDA Forest Service, Bureau of Forestry, and Game Commission because of the longer rotations that would be required under their general management strategies.

The major constraints within the model referenced to the management strategies of the various ownerships. In an effort to achieve a better balance of age classes and to sustain timber production levels on the Allegheny National Forest, the proposed management plan recommended certain production ceilings and a nondeclining even flow management policy for the Forest. An initial annual ceiling of 13.0 million cubic feet (mmcf) of sawtimber and pulpwood, as proposed, would be increased over a 50-year period until it reaches a sustainable annual level of 15.8 mmcf (USDA Forest Service 1985). To simulate these management policies, upper and lower harvest constraints were placed on the Allegheny National Forest during each decade consistent with their proposed management strategies. In addition, a nondeclining even flow constraint was used to monitor decade by decade shifts in output.

The Pennsylvania Bureau of Forestry and Pennsylvania Game Commission annually harvest approximately 1% of their even-aged forests on an area control basis as a means of establishing a normal distribution of age classes. This long term balance would be achieved by the year 2060. These agencies also manage portions of their forests on an uneven-aged basis. The Bureau of Forestry devotes 10% of its timberland to uneven-aged management; primarily as buffer areas adjacent to roads and streams. The Game Commission uses uneven-aged management on about 25% of their holdings due to a priority interest in diversifying wildlife habitats. Both agencies schedule selection harvests on uneven-aged stands on a 15-year cycle and typically remove two-thirds of the growth accruing between harvest cycles. These management policies translated into a number of constraints. On the Bureau of Forestry and Game Commission analysis areas, an upper limit constraint was set for the amount of acreage designated for even-aged management, with a second set of constraints forcing implementation of a 1% annual area control harvest on the even-aged acreage. The remaining portion of their lands was assigned to the uneven-aged prescription option.

The management strategies of the private sector were oriented to even-aged stands. Management objectives were often modified by financial and product standards, leading to a range of rotation ages of 85 to 115 years on large private tracts. Accordingly, the regional model was organized for rotation harvest of all large private properties as they entered the 80- to 110-year age classes. For large tracts, the model was allowed to make harvests at any time within this age class, subject to the further limit that, as a whole, the ownership group would harvest between 5% and 20% of its acreage in each decade. This latter constraint was believed necessary to moderate fluctuations in timber volumes marketed between decades. In order to model a relatively intensive level of management on these larger tracts, two-thirds of the large private tracts were managed with two commercial thinnings, and the remaining acreage received one thinning.

On small private tracts, it was assumed that stands were equally likely to be harvested at any time between 85 and 105 years. Accordingly, one-third of the acreage entering the 80-year age class, one-half of that reaching 90 years, and all acreage reaching 100 years were harvested to simulate this assumption. Intermediate thinnings were not allowed for the small private ownership category in order to simulate the less intensive management common to this ownership.

The timber yield coefficients for the study were based on growth and yield tables originally developed by the USDA Forestry Sciences Laboratory for the Allegheny National Forest FORPLAN model. The tables were constructed through growth simulations of inventory plot data secured from the various forest types, age classes, and site quality classes found on the Allegheny National Forest. Although the 0.5 million acre national forest is in the western portion of the Allegheny Region, the yield tables were considered to be acceptable estimates for the entire region.

Activity variables within the FORPLAN model represent the management activities (inputs) and the resulting yields (outputs). Primary activity variables were defined in the model to track acreage assigned to each prescription, sawtimber volume harvested, pulpwood volume harvested, and final harvest acreage. FORPLAN also defined internal variables to calculate timber inventory, stand average volume, and long term sustained yield capacity.

During the solution procedure, the model distributed the total acreage in each of the analysis areas among the alternative prescription-timing options. The assignments brought into solution reflected the sawtimber maximization objective function subject to the constraints imposed by the total acreage available and the complex of owner management strategies.

The model also constrained any depletion to the total forest base that might have been induced by the objective of maximizing harvested sawtimber over a finite planning horizon. Accordingly, the individual ownerships were required to carry a timber inventory volume during the last decade that at least equalled the average inventories carried during all previous decades under their management strategies. This constraint assumed that the ownerships would not intentionally deplete their growing stock, at least in aggregate. For the public ownerships, this assumption was supported by their sustained yield management attitudes. Although this assumption may be less supportable for the private sector, there has been no evidence of any private forest depletion within Pennsylvania (Powell and Considine 1982).

Results

A major increase in available sawtimber was forecast for the Allegheny Region over the 100-year period (table 1, fig. 2). Starting from a level of 280 million cubic feet (mmcf) in decade 1, the model projected near continual increases in sawtimber availability throughout the next six decades, reaching a peak volume of more than 950 mmcf in both decades 6 and 7. A modest decline was registered in the eighth decade to 880 mmcf, followed by an additional drop of 27% to the 640 mmcf level in the final two decades. Estimated sawtimber production in decades 6 and 7 were more than triple the level forecast in decade 1.

The source of sawtimber by ownership groups was in direct proportion to the amount of land controlled by each group; with 61% of the total coming from private forests, 24% from state properties, and 15% from federal lands (table 1, fig. 2). A minor shift in the private to public ratio was noted over the study period, with the first three decades having a 62:38 ratio and the last three decades a 58:42 ratio. The increased proportion of public timber during the latter decades reflected the even flow management strategies on public lands, coupled with a decline in timber availability from private lands.

Although the contributions from each forest type varied from decade to decade, overall the allegheny hardwood type was the most productive, accounting for 33% of the sawtimber while

Table 1.--Projected sawtimber harvests from the Allegheny Region by decade and ownership group, 1980-2079.

Ownership:	Allegheny National Forest	Pa. Bureau of Forestry	Pa. Game Comm.	Private small tract	Private large tract	Total
Decade			Volume *(mmcf)*			
Size *(1000 acres)*:	433.6	489.4	215.0	1,068.5	683.1	2,889.6
1	46.8	62.8	17.1	52.5	101.2	280.4
2	89.4	58.9	24.0	77.6	202.6	452.5
3	99.4	79.0	52.6	225.8	184.5	641.3
4	98.4	115.5	57.6	141.2	166.6	579.3
5	105.7	111.8	53.3	261.9	226.8	759.5
6	118.4	118.4	46.2	188.0	492.8	963.8
7	126.3	153.8	80.5	176.5	414.6	951.7
8	129.2	123.4	49.2	29.7	548.6	880.1
9	112.8	152.8	74.1	163.5	132.3	635.5
10	109.2	129.3	42.2	36.4	341.7	658.8
Total swtmbr.	1035.6	1105.7	496.8	1353.1	2811.7	6802.9
Swtmbr. from thin./sel.	97.1	223.7	191.7	0.0	472.8	985.3
Total pulpwd.	544.8	982.6	418.6	1110.8	2178.5	5235.3
Pulp from thin./sel.	146.6	503.6	256.6	0.0	1088.9	1995.7

representing 28% of the timberland. Oak type forests produced 21% of the sawtimber and represented 22% of the timberland. The remaining 46% of sawtimber originated from the 50% of timberland typed as northern hardwoods.

Over the 100-year period, 85% of the available sawtimber would be provided from rotation harvests, with the remainder coming from thinnings and selection harvests (table 1, fig. 3). The proportion of sawtimber coming from rotation harvests increased over the study period, with 59% developed from rotation harvests in decade 1, 75% in the next two decades, and 89% in the final seven decades. The estimated yield per acre for rotation harvests also increased over the study period, averaging 1.3 thousand cubic feet/acre (mcf/a) in the first three decades,

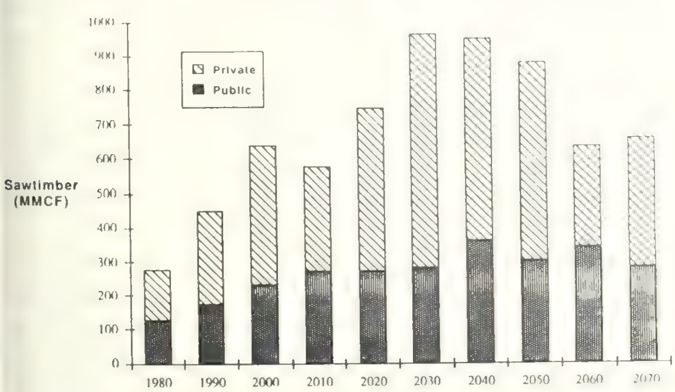

Figure 2.--Projected sawtimber availability by ownership, the Allegheny Region.

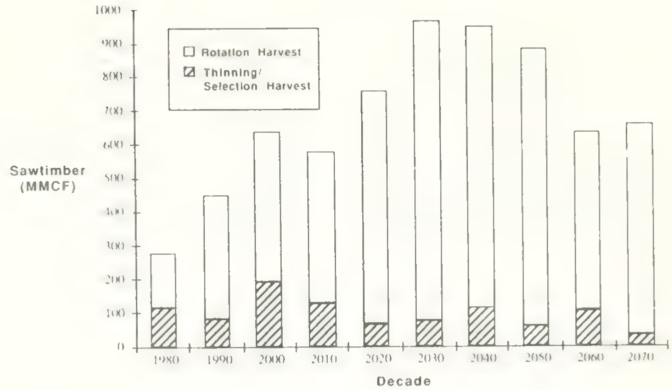

Figure 3.--Projected sawtimber availability by harvest type, the Allegheny Region.

2.1 mcf/a in the next three decades, and 2.2 mcf/a in the final four decades.

A total of 5.2 billion cubic feet of pulpwood was available for harvest during the 100-year period (table 1). The distribution of the pulpwood output by ownership groups was also in proportion to the size of the ownerships. As might be anticipated, a substantial percentage of the total pulpwood (38%) originated from intermediate thinnings and selection harvests. However, the gradual advance in the average age structure of the forest, and the associated reduction in the opportunities for commercial thinnings, resulted in a moderate decline of pulpwood availability over the study period.

Within the private ownership group, a cyclical pattern was evident in their proposed harvest of sawtimber. This was attributed to the initial imbalance in age classes held by these ownerships, in combination with their management strategy of releasing all timber to the market as it reached rotation age. A gradual increase in private sawtimber harvests was evident over the first six decades as the initial acreages of large sawtimber were harvested, followed by even larger initial acreages of small sawtimber and poletimber (table 2). However, a considerable drop in output was forecast in decades 8 and 9 as the relatively small initial acreage of seedling/sapling class material reached maturity.

The organization of public forest management strategies toward sustained production resulted in a uniform increase of public sawtimber throughout the study period. On the state properties, the increased output was attributed to the effects of the area control strategy, which resulted in a backlog of old growth stands (> 110 years). A certain fluctuation in total sawtimber output was evident, largely attributed to the variations in commercial thinning operations. On the National Forest, the nondeclining even flow constraint held output to a range of 130-158 mmcf per decade. By the fourth decade, the forest was capable of maintaining its upper limit of production through rotation harvests, which eliminated the need for commercial thinning operations. Longer rotation lengths were evident on public ownerships during decades 7 through 10, with the

Table 2.-- Age class distributions, before rotation harvest, for private and public timberland in the Allegheny Region by selected decades.

Age class		Decade 1 (year 1980)		Decade 6 (year 2030)		Decade 11 (year 2080)	
		% of timberland acreage					
1-30 yr.	Public	2.7		27.1		27.6	
	Private	7.3		29.8		35.2	
	Total		5.5		28.3		31.5
31-50 yr.	Public	24.8		13.7		15.1	
	Private	37.1		18.7		27.5	
	Total		32.3		16.9		26.9
51-70 yr.	Public	46.1		3.0		18.7	
	Private	29.8		7.0		20.2	
	Total		36.2		5.5		19.4
71-90 yr.	Public	24.2		19.8		15.9	
	Private	25.8		32.1		14.2	
	Total		25.2		29.2		14.8
91-110 yr.	Public	2.3		23.4		3.2	
	Private	0.0		12.4		2.8	
	Total		0.9		15.0		3.1
>111 yr.	Public			13.0		19.5	
	Private			0.0		0.0	
	Total				5.1		4.3

average stand age of harvested material ranging from 140-150 years.

The cumulative effect of the proposed forest growth and harvest patterns over the study period was a more balanced distribution of age classes within the aggregate forest (table 2, fig. 4). Initially, nearly 95% of the timberland was in poletimber and sawtimber size class material. By the midpoint of the study, approximately 45% of the timberland was harvested and reestablished in seedling/sapling and poletimber sized stands. The more restrictive harvesting programs on public lands resulted in about 15% of these forests extending to age classes over 90 years in age. The primary imbalance in the middle period was in the 51- to 70-year class stands (small sawtimber) that originated from the initial shortages of acreage in the 1- to 30-year class (seedling/sapling).

Over the 100-year period, an estimated 3.0 million acres of timberland was scheduled for rotation harvest. Considering that 2.8 million acres was organized under even-aged management, the first cutting cycle for this complex was completed by the tenth decade. Assuming an average rotation of 100 years, the projected schedule was consistent with a sustainable acreage harvest of 10% per decade. At the conclusion of the study, an improved balance was evident among the four basic stand size classes, with 32% in seedling/sapling, 27% in poletimber, and 41% in sawtimber stands. This general balance was found on both public and private forests.

Commercial thinnings and selection harvests were imposed on 3.5 million acres of timberland during the study period.

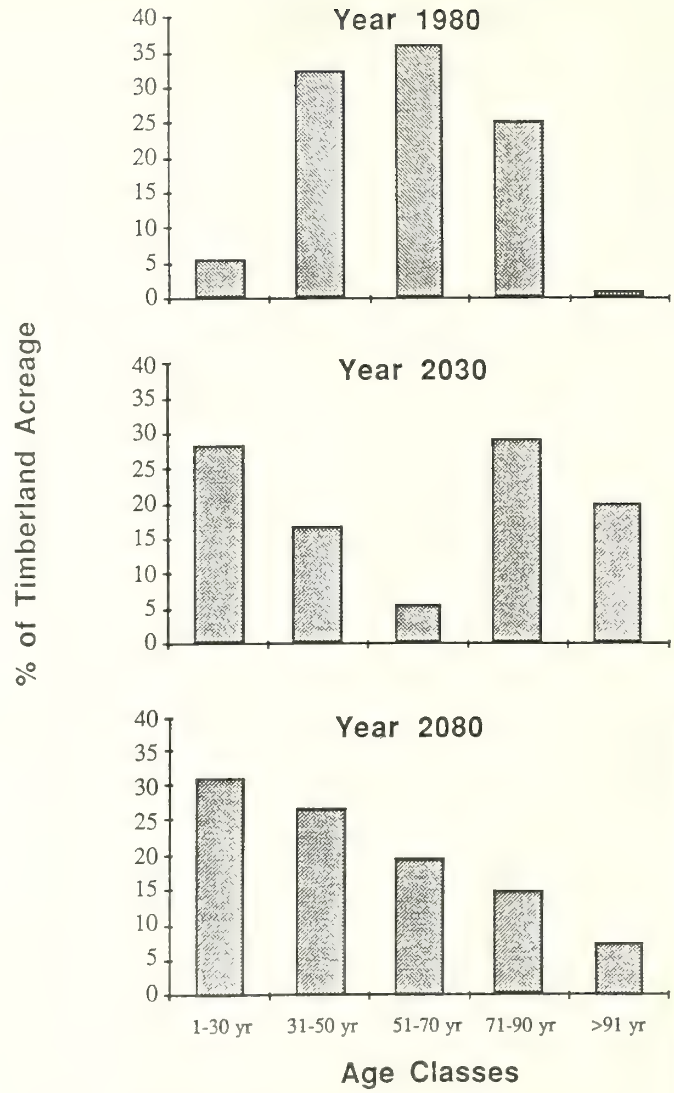

Figure 4.--Current and projected age class distributions from Allegheny Region timberland.

Nearly 65% of this activity was scheduled during the first four decades when large portions of timberland were in the poletimber and small sawtimber classes. As previously noted, none of the small tract private ownerships were scheduled for commercial thinnings.

Inventory, harvest and growth data from the FORPLAN model provided additional insights on the proposed structure of the Allegheny Region timberland (table 3). Between the first two decades, inventory increased by 7% as growth exceeded the region's harvest by a ratio of 1.35:1. From decades 2 to 6, inventory remained fairly constant, with harvests slightly exceeding growth. As harvesting accelerated and growth declined during decades 6 through 9, inventory was reduced. After the ninth decade, harvests declined and growth accelerated, as a major portion of the forest entered faster-growing age classes. At the conclusion of the study period, the regional inventory was recovering from the accelerated cutting of the middle periods.

Table 3.--Inventory, growth and harvest volumes (in mmcf) from the Allegheny Region FORPLAN model.

Period	Inventory	Harvest	Growth
1	4957.8	953.2	1290.5
2	5295.1	1104.6	1127.8
3	5318.3	1277.1	1318.8
4	5360.0	1117.8	1047.1
5	5289.3	1246.5	1152.2
6	5195.0	1473.1	945.7
7	4667.6	1399.8	1079.7
8	4347.5	1322.9	922.8
9	3847.9	1039.0	1259.5
10	4168.4	1104.7	
Average	4854.7	1203.8	1127.1

Overall, harvesting slightly exceeded growth in the region. The growth-to-drain ratio over the study period was .94:1. However, there was no indication that the projected level of harvest would deplete the regional timbershed over the long run. Based on FORPLAN estimates, the regional long-term sustained yield capacity was 1,222 mmcf per decade, which was slightly above the scheduled average harvest of 1,204 mmcf. In addition, the projected average inventory of 4,855 mmcf per decade for the region was higher than the long run stand average volume of 4,016 mmcf. Stand average volume represented the average inventory that would result from managing the forest indefinitely under the prescribed management regimes.

Discussion

A unique aspect of this study was the use of the FORPLAN linear programming system as a regional simulation model. Since FORPLAN is normally used on single ownership forests in the context of an optimization model, some comment is appropriate on its suitability for multi-ownership resource settings. Several advantages were evident.

FORPLAN is a comprehensive model, capable of simultaneously modeling the four inter-related components of an aggregate timber supply analysis outlined by Alig et al. (1984): (1) land allocation, (2) the progression of the timber inventory under the dynamics of growth and mortality, (3) harvest flows, and (4) timber inventory and management strategies.

The linear programming structure of FORPLAN permitted an explicit representation of management strategies for each ownership, including complex and inter-related long-term strategies (e.g., even-flow policies). The model also forced a careful examination of all assumptions. Regional timber supply models, by their nature, are heavily dependent on their assumptions. FORPLAN required an explicit description of these assumptions. Although it was difficult to develop management strategies for certain ownership groups, the problem is inherent to regional modeling and is not unique to FORPLAN.

The major disadvantage of FORPLAN was the necessity of specifying a single objective function for multi-ownerships (Alig et al. 1984). However, it should be noted that as the model becomes more heavily constrained by the complex of management strategies placed on each ownership, the model had less choice in achieving an "optimal" solution. Hence, the model becomes more simulation and less optimization, with the choice of the objective function less critical.

Some assessment of this study's predictions can be made from certain projections of the national hardwood markets and from other resource evaluations of the Allegheny Region. At the national level, the USDA Forest Service forecasts a tripling of hardwood products demand over the period 1980-2030 and a doubling of the hardwood sawtimber supply, leading to a predicted increase in the real prices for certain hardwood products (USDA Forest Service 1982). The primary constraints upon supply were the physical limits of the resource and a possible reluctance among private ownerships to market their timber. Overall, the national demand for hardwood products during the next 30 to 40 years should function as a complement to the region's output capability.

Previous forest surveys of Pennsylvania have shown a gradual increase in sawtimber harvests from the Allegheny Region over the past three decades (Bones and Sherwood 1979, Ferguson 1958, Ferguson 1968). A 20% increase in harvests occurred between the 1950's and the 1970's, with the initial 10-year consumptive level of 206 mmcf of sawtimber increasing to 252 mmcf by the 1970's. The industrial base study of the region's forest products industry also showed an annual sawtimber consumption of 26 mmcf in 1981, excluding log shipments to areas outside the region (Westman et al. 1985).

A positive trend in pulpwood removals has been evident in the Allegheny Region (USDA Forest Service series). Between the 1960's and 1970's, pulpwood harvests doubled, increasing from 76 mmcf per decade to 152 mmcf. Furthermore, the initial 3 years removal rate in the 1980's was 70% higher than for the same period in the 1970's (Widman 1983).

The TRAS model of the region's forest system (Strauss and McWilliams 1987) showed a potential doubling of output from the 1970's harvest rate to the 1980's availability level of 657 mmcf. A further expansion of 1.5% was estimated for the 1990's, followed by a 24% decline in the third decade (fig. 5). Over the 30-year study period, a total of 1,833 mmcf of sawtimber was identified as available, whereas the FORPLAN model predicted a total of 1,374 mmcf for the same period.

The 33% difference between the two studies was largely attributed to the alternate structure of the two models and, to a lesser extent, the alternate sources of growth and yield information used in the two models. In comparing the two models, the TRAS model had a more pragmatic format, with the forest stands moved forward in time under linear growth estimates and, upon reaching a particular dimension, automatically scheduled for harvest or intermediate thinnings. A greater flexibility was provided by the linear programming design of the FORPLAN model. Here, the optimal solution for the problem was deter-

mined through the interplay of the model's curvilinear yield tables and the selection of harvesting and thinning schedules from an array of time periods, ownership groups, and forest types. Central to this selection process was the need for maximizing sawtimber volume over the planning horizon. In addition, the model had the general choice of selecting lower levels of output during initial periods versus increased volumes from subsequent periods. In contrast, the harvests suggested by the TRAS model, though technically correct, were applied in a more pragmatic fashion, with the process largely guided by forest management strategies applied within a short-term perspective.

Both of these studies were limited in their ability to identify the quality of the proposed timber. Three general qualitative subdivisions were evident in: (1) sawtimber originating from rotation harvests, (2) sawtimber from intermediate harvests, and (3) pulpwood. The FORPLAN study anticipated that 14% of the total sawtimber volume would originate from thinnings and selection harvests, with 40% of this material developed during the first three decades. However, the sawtimber from thinnings is not as desirable as sawtimber from rotation harvests due to the former's higher cost and lower quality. Both studies found that the yield per acre from thinnings would average only 20% of the yield from rotation harvests. In addition, the TRAS model showed 60% or more of the volume in thinnings would be in tree diameters 14 inches or less, whereas rotation harvests had under 40% of its volume in this lower diameter range.

A comparison of the sawtimber forecasts from the two models with the previous trend in timber harvests (fig. 5) suggests that the future trend in output may lie somewhere between the bounds of the two studies. Essentially a greater volume of rotation harvests could be made available than originally forecast by the FORPLAN model and a lower volume of intermediate harvests would be scheduled, as forecast by the TRAS model. This compromise would also represent a logical progression in sawtimber output to the higher levels forecast by the middle of the next century.

One of the key impediments to the success of the proposed forest management strategies will be marketing the major volumes of pulpwood from this forest. As projected, an average of 523 mmcf of pulpwood will be available each decade, with

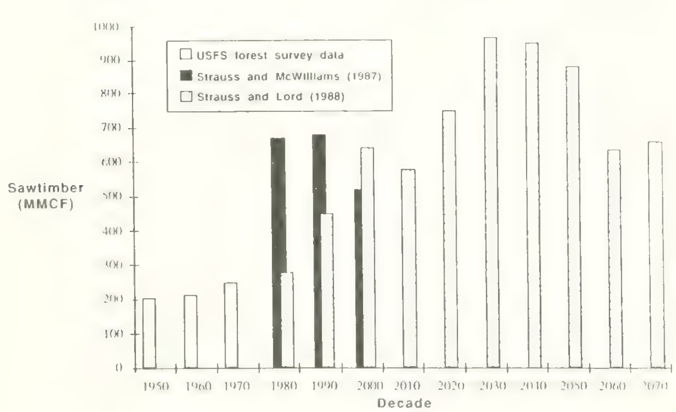

Figure 5.--Historic and projected sawtimber harvests for the Allegheny Region.

the trend in availability showing a gradual decline over the study period. The current trend in pulpwood consumption suggests a potential consumption of 230-260 mmcf during the 1980's, slightly more than one-third of the region's available harvest. Clearly, an expansion in the market outlets for pulpwood will be a prerequisite to the complete implementation of the region's forest management strategies.

Timber that is not harvested on the basis of either reluctant ownerships or unavailable markets will simply accumulate as additional inventory. In turn, added stocking will only serve to reduce the aggregate growth and quality conditions of the existing forest and lengthen the eventual rotation of mature stands. Any extension of rotations will delay the achievement of a more desirable age class balance.

Conclusions

FORPLAN proved to be an effective simulation tool in this aggregate timber supply analysis. It was flexible, relatively easy to use, and allowed for the explicit representation of a fairly complex set of assumptions. Major shortcomings included a difficulty in specifying an ideal objective function and dependence on a mainframe computer. There appears to be potential for making an expanded use of FORPLAN in modeling other multi-ownership forest regions.

Although various arguments can be made about the timing and magnitude of the predictions presented by the model, certain characteristics of the forest system support the general conclusions of this study. First, the magnitude and quality of timber resource within this region have been confirmed through a continuing series of forest surveys and updates. Second, the biologic character of this resource can not be denied, and support the increase in timber available for harvests. Furthermore, the incremental growth process has been modeled and shown to be consistent with the predicted advance of stands through their successive age classes and the eventual attainment of merchantability at prescribed rotation ages.

The most debatable aspect of the model is its capacity to accurately predict the actual volumes of timber that will be either released to or accepted by the markets. The model reflects an optimal scenario largely based on the management desires of the forestry profession. Although this advice is closely considered on public forests it may not be consistent with the future decisions of the private sector, nor with economic realities of timber markets.

A major expansion is expected in sawtimber production for the Allegheny Region. This note of optimism is supported by the increased world demand for hardwood timber resources and by this region's ability to provide a quantity and quality of timber unlike any other timbershed. In all likelihood the private sector will respond to this demand with an accelerated cut. Whether the forests will be capable of regenerating similar timber types is currently under debate. However, strong markets and premium prices for timber should provide the necessary incentive for reinvesting in this resource base.

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Modeling Regional Timber Supply in California

Bruce Krumland and William McKillop

Abstract.--The California Timber Supply (CATS) model was used to obtain projections of future potential timber harvests, growth, and inventories for private lands in California. CATS consists of an integrated system of computer modules that provides for inventory processing, data management, growth and yield simulation, linear programming solutions, and post-LP analysis.

The California Department of Forestry and Fire Protection is required by law to conduct periodic assessments of the State of California's forest and range resources under FRRAP (Forest and Rangeland Resource Assessment Program). Since 1979, funding has been provided to the University of California, Berkeley, with the objective of obtaining projections of potential future timber inventory and harvest from private lands in California on a decade-by-decade basis.

Three alternative models were considered for projecting timber inventory and harvest in California. Consideration was given to adapting the RMS 80 model of New Zealand Forest Products Ltd. (McLean 1981). Further work on this model was terminated because it was essentially an even-aged model and was tied to the concept of an "Equivalent normal forest." Consideration was also given to the TREES model which had been developed for the Timber for Oregon's Tomorrow Project (Beuter et al. 1976, Tedder et al. 1980). The Oregon Department of Forestry's IBM conversion of this model was adapted to the IBM 3090 at UC Berkeley and preliminary analyses were made (Oregon State Department of Forestry 1980). Use of the model was not pursued because a more powerful method of modeling the growth and yield of uneven-aged stands was needed. In addition, the construction of input files for TREES proved to be time-consuming and the model required comprehensive yield tables by species group for even-aged stands. Such yield tables were not readily available for California forests. It was finally decided that a new comprehensive timber supply model was required and that its growth and yield component should be based on the CRYPTOS/CACTOS type of models developed at UC Berkeley by Krumland and Wensel (Krumland 1976, Wensel and Daugherty 1985).

Research Specialist and Professor, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720.

An Overview of CATS

CATS has been designed to provide an integrated system for producing timber supply projections from regional timber inventory data. At its core are two main modules: CATSYG which performs individual stand growth and yield projections and CATSLP which builds, solves and reports on LP models. CATSLP can optionally prepare the solution basis for more detailed post-processing by CATSYG.

CATSYG

This module is a central process server that is programmed by information contained in a control file. Control information is used to set up job parameters, set data base selection criteria, control output disposition, and indicate the runtype to be performed. While CATSYG is capable of performing several operations, the two major ones used in this study are:

Calibration.--A main component of this module is a growth projection system comparable in function to the CRYPTOS/CACTOS models. In calibration runs CATSYG uses all the available data in a timber inventory to compare actual with predicted values of this system. It "suggests" calibration factors as well as producing data files that can be used in directly refitting any component equation.

Option processing.--In this runtype, each inventory unit (plot or stand data) is subjected to any number of management options. In this context, an option is described by a series of "growth simulation language" (GSL) statements. Highlights of the CATS GSL are:

- program control structures common to formal programming languages: if/then/else/endif, loops, branching, callable sub-procedures;

- ✦ math/assignment statements;
- ✦ built in macros that provide for growing the stand, flexible harvest control, sprouting/ingrowth functions, determining "point counts," and indexing;
- ✦ "read only variables" that give access to all the stand "header" information as well as every major stand/species/size class characteristic at any time during a simulation. Additional GSL statements allow users to program the values returned by these variables.

The CATS GSL was designed to provide flexibility to produce any type of yield forecast without being hampered by built-in software limitations. This innovative development will be described in more detail in a forthcoming paper.

CATSLP

This module takes special yield files produced by CATSYG, creates LP tableaus, solves the LP, and produces tabular and graphic reports. Initially, this module creates a programmable accounting tableau of major variables of interest. The implementation used the usual "stand acreage" constraints and growth, harvests, and standing inventory volumes cross-classified by owner and species group (conifer or hardwoods). Run-specific constraints and objectives are introduced by operations on the accounting tableau variables.

IMPLEMENTING CATS FOR CALIFORNIA

CATS was designed to produce regional timber supply projections for California. In its present form it is set up to deal with the USDA Forest Service "Forest inventory and analysis" data (Bolsinger 1986), commonly referred to as the "Forest Survey" data. It could, however, be adapted to process inventory data for individual private properties or tracts of public land. Information on the most recent USDA Forest Surveys are reported by Colclasure et al. (1986a, 1986b), Hiserote et al. (1986), and Lloyd et al. (1986a, 1986b).

Forest Survey data for California cover more than 1,200 sample points each of which consists of five sample plots. Consideration was given to combining sample points into more or less homogeneous stand types, but it was decided that this combining would introduce an element of inaccuracy and lack of realism. Accordingly, each sample point was treated as an individual stand in the CATS model. The forest survey data were used by CATSYG to calibrate the growth simulation component.

Northern California Regions

Each sample point is identified by the county in which it is located. Ideally, an analysis such as this might be carried out on a county by county basis, but lack of data required that the sample points be aggregated into five regions in northern California. These are:

1. The North Coast region consisting of Del Norte, Humbolt, Mendocino, and Sonoma counties.
2. The Northern Interior region consisting of Siskiyou, Modoc, Trinity, Shasta, and Lassen counties.
3. The Sacramento region consisting of counties south from Tehama and Plumas to Sacramento and El Dorado.
4. The San Joaquin region consisting of counties from San Joaquin, Amador, and Alpine south to Kern, Tulare, and Fresno counties.
5. The Central Coast region consisting of counties from Marin and Solano south to San Benito and Monterey.

Southern California is listed by the USDA Forest Service as a survey region, but the number of sample plots in southern California counties are too few to permit analysis.

Forest Ownerships

The "Forest Survey" data cover only private ownerships and non-U.S. Forest Service public land in California. At the present time, the CATS model is set up to process data for private land but could be adapted to forest inventories for individual National Forests or groups of National Forests. Two classes of private ownership are recognized in the CATS model: (1) industrial forest land, and (2) nonindustrial private ownerships. Non-industrial ownerships under 50 acres in size were excluded from the timber-producing land base.

The number of acres by ownership and region that each sample point represents was provided by the FRRAP staff of the California Department of Forestry and Fire Protection.

Forest Management Practices

A survey of industrial and non-industrial forest management practices was conducted to provide a realistic basis for the specification of management options.

The current version of the model uses nine types of basic management options for each decade in the 1985-2055 period of analysis. The nine options are:

A. Do nothing (no harvests, just let the stand grow).

B. Special zones. Cut half the merchantable volume over 16 inches dbh, ensuring that the remaining stand meets the legal minimum stocking standards. Stands must have at least 5,000 board feet to the acre to be considered for harvesting.

C. Poor sites. Do an "economic" clearcut; regenerate to meet legal minimum stocking standards. Repeat clearcutting and regeneration whenever standing volume exceeds 5,000 board feet per acre.

D. Well-stocked even-aged young growth conifer stands with at least 80 percent of the stand volume in trees of 11 inches dbh or greater. Clearcut and regenerate with 400 conifers per acre.

E. Commercial thinning of well-stocked young growth conifer stands with a clearcut final harvest 20 years later and restocking with 400 conifers per acre.

F. Well-stocked uneven-aged young growth conifers. Partial cutting to maintain current stocking and dbh distribution.

G. Non-industrial private stands not described above. Remove one-third of the standing volume in trees 16 inches dbh and greater, provided the conifer harvest volume is greater than 3,000 board feet per acre. Meet minimal stocking standards following harvest.

H. Industry old-growth stands or marginally stocked conifer stands or predominantly hardwood (merchantable) stands on good sites. Clearcut and regenerate with 400 conifers per acre.

I. Industry stands not described above. If stocked with conifers, attempt to convert the stand to a viable unevenaged structure. If this is not feasible, clearcut and regenerate.

J. Industry non-stocked lands or predominantly unmerchantable hardwood stands on better sites. Provisions were made to clearcut and regenerate all of these stands in the first 3 decades.

It should be noted that all options were coded so that all post-harvest regeneration practices were designed to leave stands with legally acceptable stocking.

The application of a particular option to a specific stand may occur during any of the seven decades in the projection period. Thus if the timing of each management practice is considered as well as the type of practice, there are numerous options to draw from in selecting the prescription that is appropriate for a given stand type, but irrelevant options were, however, eliminated on the basis of experience.

It should be noted that in current runs of models, hardwood competition is eliminated from industrial clearcut lands. Industry representatives indicated that brush and hardwood control would normally be practiced in regenerated stands. It should also be noted that utilization standards were imposed on harvest practices with the minimum tree dbh tallied in final (clearcut) harvests set at 16 inches in the first decade and declining to 9 inches in the fourth decade.

CATSLP Implementation

The CATSLP module was set up to treat decadal regional growth, harvests, and inventory volumes cross-classified by owner (industrial, non-industrial) and species group (conifers, hardwoods) as primary accounting variables. The relative "weights" given to hardwoods in the objective functions was 30% of conifer values.

Current runs of the model were designed to maximize volume or basal area harvest subject to constraints on the terminal inventory and numerous flow requirements. The use of linear programming makes it comparatively easy to expand the model to a financial optimizing system.

The linear programming structure also makes it easy to examine the implications of different types of constraints with respect to such things as changes in harvest level from period to period or the acreage of a particular timber type that can be subject to a given harvest/silvicultural regime.

Projections of Inventory, Harvest, and Growth

Projections of timber inventory, average annual potential harvest, and average annual growth were developed by region and ownership for seven decades: 1985-1995, 1995-2005, 2005-2015, 2015-2025, 2025-2035, 2035-2045, and 2045-2055 and compared with estimates for the 5-year base period 1980-85. Each period runs from the middle of the first year to the middle of the last year in the period.

Timber inventory estimates are for the middle of each period. Annual growth includes ingrowth into the diameter classes represented in the standing volume estimates as well as increment in that standing volume. Harvest levels for the 1980-1985 base period were generated by the model under the constraint that conifer harvests had to be equal to the estimate of the average 1975-85 levels provided by the State Board of Equalization. (The 1975-85 period encompasses the peaks and troughs of the lumber market in recent years.)

Accurate estimates were not available for hardwood levels, so the 1980-85 hardwood cut was constrained to be no more than 15 percent of the conifer cut.

Several types of basic computer runs were made for each region to span the types of aggregate management strategies likely to prevail in different regions and ownerships. Runs TB2, TC2, TB4, TC4, TB7, and TB7 were used for the North Coast, Northern Interior, Sacramento, and San Joaquin regions. The total private conifer harvest (from industrial and non-industrial lands combined) was maximized over the first two decades (1985-2005) in TB2 (board feet) and TC2 (cubic feet), over the first four decades (1985-2025) in runs TB4 and TC4, and over all seven decades in runs TB7 and TC7. These runs were subject to constraints that (1) the conifer standing volume in the final decade (2045-2055) could not be less than 80 percent of the 1980-85 level, (2) the average annual conifer cut on industry lands in 1985-2005 could not be less than 80 percent of its 1980-

85 level, and (3) the hardwood harvest in all forecast periods from 1985-1995 onwards could not exceed 25 percent of the conifer cut. Also, it was required that conifer cuts be equal in each decade over the maximization period to facilitate comparisons between different runs. Runs were also made which maximized the conifer cut from industrial lands alone.

The current level of conifer growth in the Central Coast region is significantly greater than the harvest level; so, it would have been unrealistic to use the normal formulation of the model for that region. M7 was used along with a variation of it, M8. Run M7 maximized the sum of the conifer cuts (in square feet of basal area) over the seven decades plus the final inventory (in terms of basal area) in 2045-2055 subject to the constraint that the average annual conifer cut could not be less than the 1978-85 level. In run M7, the harvest level had to be the same for all decades in the maximization period. In run M8 it was permitted to vary by plus or minus 25 percent from decade to decade.

Although it would have been possible to make many more alternative runs of the model, budgetary limitations made it necessary to limit its use to the runs described above. In the judgment of the investigators, those runs (with their associated constraints) are the most useful scenarios that could be constructed within the limits of the research budget. Runs TB7 and TC7 respond to the often-heard query: "Can current levels of private conifer timber harvest in California be maintained?" Runs TB2 and TC2 reveal the maximum levels of conifer harvest that appear to be possible over the next two decades. Runs TB4 and TC4 are intermediate between the two, and in the opinion of the investigators give a more likely indication of potential future timber harvests, inventories, and growth.

Overview of Harvest Projections

The level of private timber harvest in California has undergone a secular decline since the mid-fifties when it was approximately 5 billion board feet per year. In 1982 it reached the lowest level on record of 1.5 billion. The results of various runs indicate that this downward trend has been arrested and that future standing timber volumes will permit an average cut level of over 2 billion board feet per year for the foreseeable future.

There will, however, be a significant change in the type and location of timber harvests in the future. In general, logging of old-growth from non-industrial lands preceded harvest from lands owned by the forest industry so that non-industrial young growth is at a more advanced stage than forest industry young growth. Thus, as forest industry harvests its remaining old-growth timber and larger young-growth, it will turn increasingly to non-industrial young growth stands as a source of supply. The transition from an old-growth timber resource to a young growth one has been underway for the last two decades on private lands in California and will continue for the next decade or so. This will lead to substantial changes in wood processing technology but the impact on regional forest economies will be mitigated, provided planned harvest levels of old-growth timber from National Forests are achieved.

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Implementing an Ownership-Behavior Simulation of Private Sector Timber Supplies

Robin Marose, Raul Tuazon, and Lawrence S. Davis[1]

Abstract.--This paper discusses the applicability of optimization, general equilibrium, and simulation models for statewide assessment and policy analysis, and describes in detail the simulation system developed by the Forest and Rangelands Resource Assessment Program. The system's capabilities are demonstrated for two different scenarios that affect future timber supply from private lands in the North Coast Region of California.

The Forest and Rangelands Resource Assessment Program (FRRAP) is legislatively mandated to periodically assess the status of California's public and private forest and rangelands, and to identify emerging trends that are likely to affect future condition and use. The FRRAP Information and Analysis System (fig. 1), including the CALPLAN simulation model (Davis et al. 1987), has been developed to meet this mandate. The System projects future conditions under a variety of assumptions to meet the objectives of the assessment or analyze legislation and other state policy options that address current or emerging issues.

This paper briefly discusses the applicability of optimization, general equilibrium, and simulation models for statewide assessment and policy analysis. An overview is provided of the FRRAP simulation approach, which uses behavior classes to represent variation within ownership groups. A more detailed discussion of the System is provided in the 1987 FRRAP Assessment (California Department of Forestry and Fire Protection 1988). The System's capabilities are demonstrated for a continuation of current trends scenario, as described in the Assessment, and an alternative scenario that affects future timber supply and wildlife habitat on nonindustrial forestland in the North Coast Region of California.

FRRAP ANALYTICAL MODELING REQUIREMENTS

The development of the FRRAP analytical system was based on the following criteria:

[1]*Operations Research Specialist II, Staff Resource Economist, California Department of Forestry and Fire Protection, Forest and Rangelands Resource Assessment Program, and Professor of Forest Management, University of California, Berkeley.*

1. State-wide applicability for both forest and rangelands, while maintaining county level resolution.
2. Consideration of the environmental consequences, as well as the benefits of commodity production from land management activities.
3. Adequate representation of the unique characteristics of the multiple public and private ownerships present in the state, as well as the variation that exists within each ownership.
4. Flexibility and applicability to the wide range of issues and options pertinent to forest policy in California at the state level or for any distinct region of the state.
5. Utilization of an intuitively satisfying methodology with explicit assumptions to aid in communicating with county governments, interest groups, or other parties.
6. Utilization of the best available existing data sources, and have the capability to integrate the results of current and future research.

CHOICE OF MODEL

A variety of different approaches and models are available for assessment and policy analysis. Based on the stated criteria, optimization, general equilibrium, and simulation approaches were evaluated to determine the best approach to meet the FRRAP mandate.

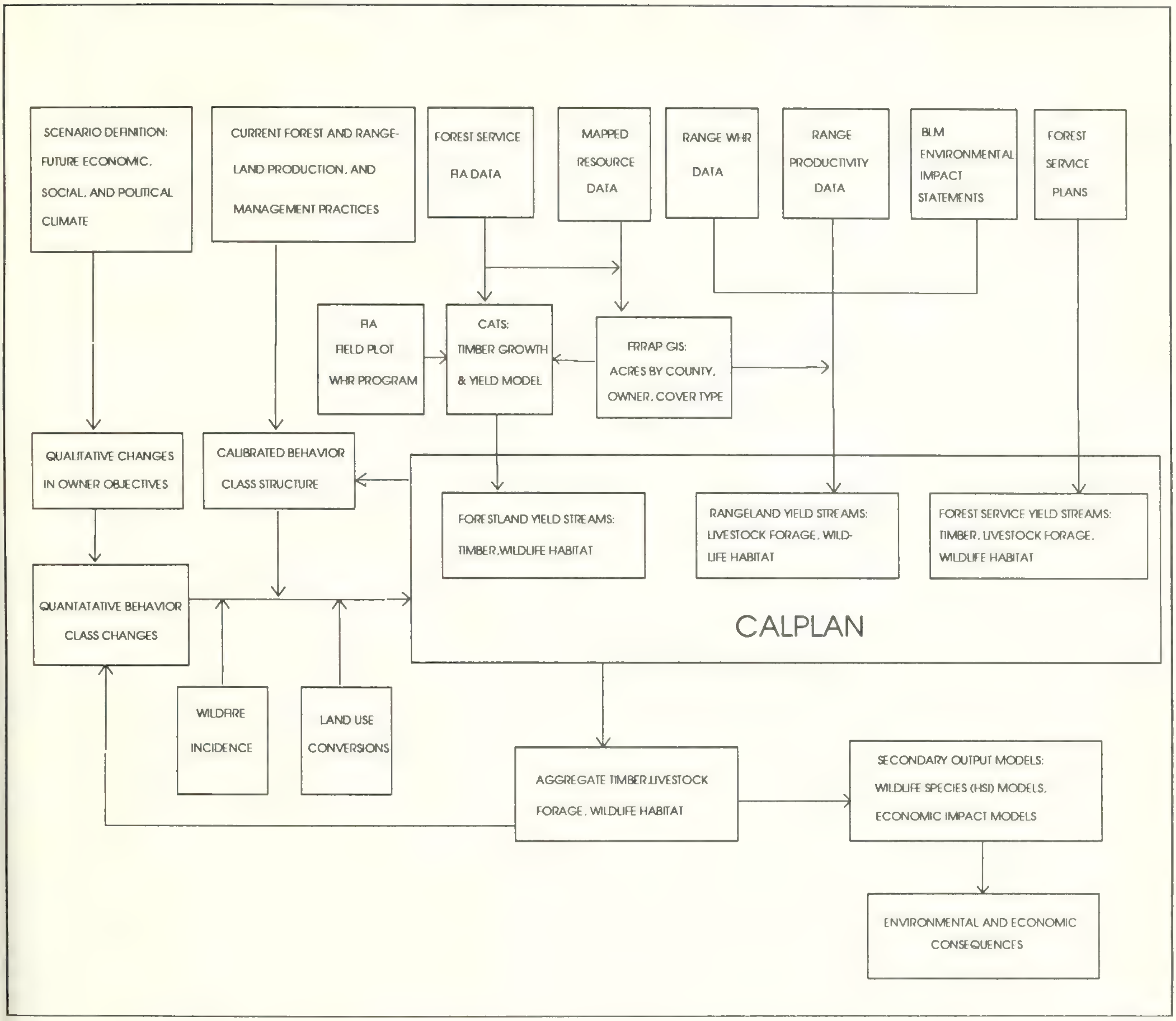

Figure 1.--The FRRAP information and analysis system. Source: California Department of Forestry and Fire Protection, 1988.

Optimization Models

Commonly used optimization approaches such as linear programming have land management and resource production activities driven by an objective function that maximizes financial returns or commodity production or minimizes cost, for example. This may be appropriate for a single landowner with well defined objectives and constraints, but becomes more problematic when applied to California, with a wide diversity of owners. Even for a single owner such as a national forest, experience has shown that attempts to produce a realistic model formulation can lead to large, costly, complex models that are often not understood or trusted by outside parties.

Deriving a realistic objective function for California is impossible now, given the importance of recreation, wildlife habitat, sub-division for housing, and agriculture, as well as timber production as viable land use options. Also, people may own land for aesthetic reasons, making forecasts based on maximizing returns from commodity production inappropriate.

In addition, the complex pattern of social and political pressures in the state imposes constraints on viable management practices. These pressures affect management in a unique fashion for different counties and ownerships, and will continue to evolve over time. Even if the constraint set representing these pressures could be somehow quantified, the model would be too large, costly, and complex to meet the requirements of FRRAP.

General Equilibrium Models

General equilibrium models are another class of models used in forest assessment and policy analysis. These models usually focus on prices and output levels of various resource commodities under different market conditions. General equilibrium models are econometrically derived, based on a set of interrelated equations that describe the underlying structure of the market. The main advantage of these models is the ability to incorporate and demonstrate market feedback affects due to changing output levels, through the structural equations.

The FRRAP modeling requirements limit the applicability of general equilibrium models, however. Production cost and demand data are not available at the county level. Non-priced outputs and other factors dominate the changing pattern of land use and ownership in California. It is also difficult to explicitly recognize multiple land ownership and use patterns within the context of general equilibrium models.

Simulation Models

Simulation models are commonly used in forestry applications for projecting timber yield, wildlife habitat, and environmental impacts such as sedimentation that result from management practices. Common applications of simulation include generating yield streams required for use in optimization models, or portraying the trade-offs of alternative management options available to a small landowner.

Application of simulation at the state level is difficult given that aggregation of owners is necessary for a workable system. Representing individual owners in the model would be an impossible task, while simulating typical management regimes of a few ownership groups would be too simplistic. The simulation approach used by FRRAP, however, uses an innovative concept of behavior classes to sub-divide broad ownerships into functional groups based on unique objectives, constraints, management practices, and yields.

Advantages of the FRRAP Simulation Approach

Relative to other approaches, the main advantages of the FRRAP simulation approach include:

1. Direct representation of the variation within broad ownership groups (criterion #3).
2. The simulation model itself relies on a relatively simple methodology that can be communicated to outside parties (criterion #5).
3. Scenario simulation, described in subsequent sections, involves translating broad assumptions about future social, political, and economic conditions into changes in owner behavior based on historical trends and expert opinion. Since the process is performed outside the model, the critical decisions in generating a scenario can be made explicit and easily communicated to outside parties (criterion #5).
4. Expert assessments of future demographics, economic conditions, politics, legislation, federal and state policy can be used to generate alternative future scenarios (criterion #6).

Disadvantages of the FRRAP Simulation Approach

Relative to other approaches, the process of translating the broad assumptions that define a scenario into changes in owner behavior puts responsibility on the analyst rather than the model. Whether this is a disadvantage depends on the ability of the analyst to consistently and realistically perform this key step.

A disadvantage is that the model has no internal market or behavior feedback mechanism. This can lead to unrealistic fluctuations in harvest levels between periods. Since the model is simple, fast, and inexpensive, it is possible to alleviate this problem, with the analyst providing the feedback mechanism by adjusting behavior changes in an iterative manner to produce a reasonable harvest schedule.

Finally, the approach is currently an unconventional modeling strategy and has not had the degree of testing and scrutiny in its application relative to other approaches.

THE FRRAP SIMULATION APPROACH

To simulate the wide range of resource management behav- ior prevalent in California, forestland owners are characterizec as belonging to one of several behavior classes. A behavior class represents landowners who share similar views regarding thei land as an economic asset, have similar management objec tives, face similar constraints that affect ability to invest, and therefore, utilize similar management practices. The use o behavior classes adds flexibility in simulating differences i management between, for example, industrial forestland own ers with and without sawmills, or between the variety o nonindustrial forestland owners. Examples of behavior classe include the intensive grower that produces a stable flow of ra material over time and invests heavily in regeneration and stan improvement practices, and the holder that owns land for variety of reasons and does not actively manage for timbe production.

Yield streams must be generated for each behavior class fo inclusion in the simulation model. Since each class has we defined objectives and constraints, optimization methods ca be used to project resource production and the resulting env ronmental consequences for each class. The key point is th optimization is performed initially only to generate yie

Table 1.--CALPLAN behavior class characteristics.

	Capital Asset Manager	Grower	Steward	Holder
Goals	High return on existing capital; high liquidity; diverse portfolio	Stable income, raw material supply; land stewardship	Multiple use; maintenance or enhancement of a variety of resource values; damage avoidance and mitigation	Primarily non-timber goals; homesites, recreation, investment, estate
Planning period	Short- to mid-term, 5-20 years	Mid- to long-term; 15-100 years	Mid- to long-term; 15-100 years	Short-to long-term; 5-100 years
Discount Rate	High	Moderate	Low to moderate	Low to moderate
Constraints	Few on harvest; cash flow and other investments; opportunities	Maintain material supply, income; capital reserves for future needs	Timber harvest cannot degrade other resource values	Shared constraint against regular harvesting
Management	Short conversion period, high basal area harvest	Moderate conversion period, moderate basal area harvest, stand improvements	Long conversion period, light basal area harvest, stand improvements, some areas withdrawn from harvest	No timber harvest

streams to incorporate into the CALPLAN simulation model. Yield streams are also generated for each possible change in ownership and/or behavior class in future periods. These changes can occur through direct land sales or transfers, or changing behavior in response to external forces.

CALPLAN is calibrated by deriving an initial distribution of forestland acres among behavior classes that results in levels of production consistent with what is currently observed at the county level. The calibrated behavior class pattern is constant for all scenarios. Scenarios are simulated by translating assumptions related to future political, economic, and social conditions into changes in ownership and behavior class structure. The ownership and behavior class changes drive the model, generating estimates of resource production and environmental consequences over time.

CALPLAN Forestland Owners

Major forestland owner groups are separated in CALPLAN in order to provide unique estimates of future resource production and condition, making it possible to target policies at acreage more specific than the entire forestland base. Four major forestland ownership groups are identified in CALPLAN: Forest Service, other public, timber industry, and nonindustrial private. Since Forest Service outputs are taken from draft management plans, the use of behavior classes for simulation purposes applies only to the other three ownerships.

CALPLAN Forestland Behavior Classes

Forestland behavior classes used in CALPLAN are based on previous work on California landowners (Casamajor et al. 1960, Romm and Washburn 1985, Romm et al. 1987, Teeguarden et al. 1960). Behavior classes are defined by four factors: dominant goals, length of planning horizon, real discount rate used in decision-making, and internal constraints on behavior. These four factors influence resource management-related investment and disinvestment decisions.

Four major behavior classes are used, with levels within each major class. The major classes are Capital Asset Managers, Growers, Stewards, and Holders. The four classes are described in the following section and summarized in table 1.

Capital Asset Manager

The Capital Asset Manager behavior class (CAM1-CAM3) is comprised primarily of national or multi-regional integrated forest product firms that aggressively manage their lands and move capital between regional operations. Mid-sized California forest products companies that are not primarily landown-

ers, but will occasionally purchase land for the timber inventory, may also be part of this class. Resort, residential, and commercial developers may also be included.

The primary timber harvesting, management, and investment behavior of Capital Asset Managers is driven by the strategic capital value of the existing timber inventory. The criteria for investment are modeled to reflect the spectrum of possible behaviors within this class. At one end of the spectrum are owners (CAM1) with extremely high rates of return and short planning horizons, who are likely to reinvest only the minimum required by law into timberland condition. At the other end are owners who aggressively manage their timberlands for current and future yield, sustaining high levels of investment in timberland (CAM3).

Grower

Large scale industrial tree farmers would generally be classified in the Grower behavior class (GROWER1-GROWER2). This class includes mid-sized, integrated California forest products companies, insurance firms and pension funds, and farmers and ranchers with forest woodlots.

Growers usually look to their forest lands for a sustainable income or supply of raw material over a mid- to long-term planning horizon. Two levels of growers (GROWER1 and GROWER2) are used to represent the range of investment within the class.

Resource Steward

Resource Stewards are primarily those owners whose land management behavior is driven by multiple use objectives, and timber production is not a dominant goal. This class includes rural homesteaders and wealthy, well-educated "new" landowners. In addition, many areas not available for conventional timber harvest, such as scenic corridors or some parks, are managed in a stewardship fashion.

The dominant goal can be a variety of individual or multiple goals, including wildlife habitat preservation, maintaining scenic areas, and improving recreational possibilities. Timber production can be one of the goals as well, but is not allowed to interfere with other objectives.

Holder

The Holder class consists of owners who, based on their own goals and constraints, feel that forest land with standing timber produces greater benefits in the near- to mid-term than if the timber were cut. Owners look to their lands for many non-income related benefits, such as amenity, recreational and wildlife values, capital appreciation of land and timber together for real estate value, as well as for a homesite. There are many varied goals and owner types from homeowners, recreation retreats, land speculators, developers, or estate trusts.

Behavior Class Yield Streams

Field plot and aerial photo data from the Forest Inventory and Analysis PNW Portland group, coupled with the FRRAP Geographic Information System, provided the basis to represent the current distribution and condition of forestland in terms of species composition, volume, site quality, and stocking levels. The data are used to derive a unique inventory structure for each region and owner combination.

The growth and yield component of the California Timber Supply (CATS) model (Krumland and McKillop 1987) provided a way to grow individual field plots into the future and simulate the range of management practices currently observed in California. The model has growth functions derived from remeasured trees from the FIA surveys, providing a consistent method of projecting growth for all species and locations in the state. Outputs from the CATS model include harvest, inventory, growth, and mortality by species group.

A computer program was linked to CATS that determines the Wildlife Habitat Relationships (WHR) cover type based on species composition, and successional stage based on tree size and crown closure for each FIA field plot as it is managed through time. This allowed a unique WHR type/successional stage structure yield stream to be derived for each region, owner, and management regime combination.

Initially, timber and wildlife habitat yield streams were generated using CATS for each management regime. Even-age regimes are defined based on the conversion period required to harvest existing merchantable stands, and regeneration intensity. Uneven-aged regimes are defined based on percent of basal area removed during 10-year entries, and whether stand improvement practices such as removal of suppressed trees and undesirable species are performed.

The characteristics of typical even- and uneven-aged management regimes used by each behavior class are shown in table 2. For example, the GROWER2 uses even-aged management consisting of a 50-year conversion period and intensive regeneration practices. Uneven-aged management for the GROWER2 consists primarily of removals of 33 percent of the basal area during 10-year entries, with stand improvement practices. Understocked and hardwood dominated areas are converted to fully stocked conifer stands over a 10-year conversion period using intensive regeneration practices.

Behavior class yield streams are derived based on proportionate use of management regimes by each class. Relative use of even- versus uneven-aged regimes varies by behavior class and by region. In the North Coast Region, even-aged management is more prevalent than in other regions of the state, for example.

Yield streams are also derived for behavior class and ownership changes. For example, land transferred from a nonindustrial holder to an industrial GROWER2 is simulated by growing the inventory to the mid-point of the period of transfer, and then applying the management regimes typical of the GROWER2 class.

Table 2.--Management regime characteristics by behavior class.

	Even-aged management		Uneven-aged management		Understocked & hardwood stands	
Behavior class	Conver. period	Regen. intensity	Basal area removal	Stand improv.	Conver. period	Regen. intensity
CAM1	10	Minimum	75%	No	10	Minimum[1]
CAM2	20	Minimum	50%	No	20	Minimum
CAM3	20	Intense	50%	No	10	Intense[2]
GROWER1	50	Minimum	33%	Yes	50	Minimum
GROWER2	50	Intense	33%	Yes	10	Intense
Steward	100	Intense	10%	Yes	100	Intense
Holder	No cut	--	No cut	--	--	--

[1]Minimum regeneration intensity for treatment of understocked and hardwood dominated stands implies that restocking is performed only if the operation can pay for itself.

[2]Intensive regeneration intensity for treatment of understocked and hardwood dominated stands implies that re-stocking is performed regardless of whether the operation can pay for itself.

Calibration

CALPLAN is calibrated to reflect current conditions, based on historical timber harvest levels, and current ownership and management patterns. Forestland is assigned to behavior classes to generate levels of outputs that are consistent with what is currently observed. The calibrated behavior class structure represents the ownership and management pattern for the decade 1980-1990, and provides a common basis for subsequent CALPLAN simulations.

Briefly, calibration was accomplished in a two-step process. First, initial behavior class proportions were estimated for each owner group in each county, based on ownership surveys, interviews, Department of Forestry and Fire Protection timber harvest plan records, and Board of Equalization timber tax harvest records. The process was a county-by-county, owner-specific, intensive allocation of proportions across behavior classes consistent with existing, available information. These proportions were then systematically adjusted so that the resulting timber harvest levels matched the 1978-1985 average annual harvest for a particular owner group in a particular county.

Scenario Simulation

Scenario simulation is a four-step process. First, the future economic, social, and political climate of the scenario is defined. Based on the scenario, qualitative changes in owner objectives are identified. The third step involves translating the qualitative changes into actual quantitative changes in the relative proportions of acres in different behavior classes. Fourth, the impacts of these changes are estimated with the CALPLAN model.

A basic premise of CALPLAN scenarios is that future conditions depend on how forestland owners are likely to respond to a wide array of market and non-market trends, particularly regarding current harvest and investment in future productivity. Within this context, current and future stumpage and lumber prices along with resource capability play a role, but are not the sole determinant of investment or future timber supplies. In certain circumstances, social and political considerations and trends play stronger roles in landowner behavior. Investment and disinvestment decisions will be based on the interaction of these trends. The local and regional variation in the trends will also influence future conditions.

Future trends that are likely to affect landowner objectives and behavior are quantified to the extent possible, or described qualitatively. Quantification and description is based on a variety of sources, including government and private statistics and projections, academic research, interviews and contacts with private industry, Forest Service, Department of Forestry and Fire Protection, other agencies and interested groups. The 1987 FRRAP Assessment provides most of the historical detail on which trends are based. This first step serves to define the context of the scenario.

The second step involves projecting how landowner objectives and behavior may change within the context of the current scenario. Some trends are indicative of shifts in owner objectives. Depending on their circumstances, landowners can be expected to change their behavior in response to projected trends. For example, in a simple scenario with rapidly rising stumpage prices in the short-run, some landowners can be expected to respond by increasing harvesting activities. The degree of change in response to price trends will vary by county based on unique social and political characteristics of local communities.

The third step involves making explicit changes in the relative proportions of land held and managed by different owners and behavior classes. These changes arise through direct land transfer or modification of the objectives and/or constraints of individual owners. The changes are made on a county-by-county basis, from the calibrated behavior class pattern.

Finally, the proportions are entered into CALPLAN and the results are examined. Iterations may be necessary to incorporate feedback responses consistent with the trends that constitute the scenario. The purpose of this fourth step is not to produce a pre-determined output level but to generate trends in output flows that are consistent with the scenario.

The strength of the scenario simulation process lies in the explicit nature of assumptions about trends, changes in land use, geographic variability, and the rationale behind such choices for the scenario. Consequently, the strength of simulations depends on the plausibility of any particular scenario, and the consistency with which it is implemented.

ALTERNATIVE SCENARIOS

Two scenarios will illustrate the CALPLAN simulation process. For simplicity, the current discussion focuses on nonindustrial lands in the North Coast Region of California. Nonindustrial owners have less than 5,000 acres of forestland and no full time timber management staff. The North Coast Region, consisting of Del Norte, Humboldt, Mendocino, and Sonoma Counties, accounts for a substantial portion of the state's timber output, but is also in a state of transition away from timber dependency.

The first scenario has been extensively developed as part of the Assessment. The second scenario demonstrates a simple "what if" analysis that could be used for policy, sensitivity, or trade-off analysis.

Scenario One: Continuation of Current Trends

For the continuation of current trends scenario, the following major factors are expected to influence future timber supply in California:

Social factors: diversification and internationalization of the California economy; increased demand for a wider variety of forestland outputs; continued settlement, conversion, and fragmentation in the forest fringe; and higher reservation price for timber from nonindustrial lands associated with higher relative values placed on other ownership attributes.

Political trends: increasing institutional conflicts between levels of government, agencies, and interest groups; increased concern and litigation over timber harvesting activities; and decreasing political influence of natural resource commodity industries in an urban, high technology, service-oriented economy.

Market trends: slower long term growth in demand and real prices for lumber and wood products, with continued short-term volatility; continued competitive pressure from the Pacific Northwest, Canada, and the Southeastern U.S.; technological improvement in sawmilling and manufacturing; decreased comparative advantage from specialty old-growth products; little development of new products and markets; and scarce capital for investment due to lower profit margins and high budget and trade deficits.

If current trends continue, then a less than favorable economic and political climate for high investment levels in timber production in California can be expected, over the long-term. Statewide, investment in intensive timber production is likely to decrease over the next two decades, due to rising production costs and regulatory constraints, coupled with slow to moderate real price increases for lumber. However, landowner behavior can be expected to vary by region within the state.

In the North Coast, biological and economic conditions will be relatively more conducive to active forest management. In the short term, timber harvest and investment should remain relatively high, on both industrial and nonindustrial lands. On the other hand, continued population growth, changes in local attitudes, especially among landowners neighboring areas to be harvested, and heightened local and statewide attention paid to remaining old-growth stands in private ownership, are likely to affect landowner decisions regarding investment in intensive management, particularly in Sonoma and Mendocino Counties. Doubts by owners about the probability of managing and harvesting timber over the long-run may dampen investment, as will any rise in production costs not offset by rising lumber prices. Although nonindustrial lands may be harvested as they change hands, new owners are likely to have different values and higher reservation prices than previous owners.

Scenario Two: Active Nonindustrial Forestland Management

A second, relatively simplistic scenario has been developed to illustrate the "what if" approach, focusing on nonindustrial private forestlands in the region. It demonstrates how a scenario would be modeled to reflect active timber management by a substantial portion of the nonindustrial sector, for example, in response to a successful policy or program. It also shows how sensitivity analysis, with respect to behavior class changes, could be done in CALPLAN.

SCENARIO RESULTS

Behavior Class Changes

Proportionate changes in acreage between different behavior classes were made, on a county-by-county basis, to simulate landowner responses for each scenario. Table 3 presents the net effect of the two scenarios on land ownership by behavior class for nonindustrial forestland owners in the North Coast.

If current trends continue, nonindustrial forestland owners would be expected to increase timber management activities, responding to a growing inventory, active industry log buying programs, and high values represented by redwood. The amount of land owned by the Holder class would be expected to decline, with increases in the Grower and Steward classes. Sixty-five percent of the nonindustrial forestland would remain in the Holder class, however. For the second scenario of more active nonindustrial timber management, substantially higher proportions of land would shift to the CAM3 and GROWER2 behavior classes, and a lower proportion would be in the HOLDER class. Table 4 shows how these proportions would vary by county.

Timber Inventory, Growth, and Harvest

Projected timber inventory, growth, and harvest based on the simulated behavior class changes for the two scenarios are

Table 3.-- Proportion of nonindustrial private forestland acres, by behavior class, North Coast Region, for two scenarios.

		Percent of acres		
Scenario	Behavior class	1980-1990	1990-2000	2000-2010
Scenario #1	CAM1	0%	0%	0%
	CAM2	3%	3%	3%
	CAM3	6%	6%	6%
	GROWER1	6%	11%	12%
	GROWER2	0%	2%	3%
	Steward	4%	7%	10%
	Holder	80%	71%	65%
	Total	100%	100%	100%
Scenario #2	CAM1	0%	0%	0%
	CAM2	3%	2%	2%
	CAM3	6%	17%	28%
	GROWER1	6%	5%	3%
	GROWER2	0%	12%	25%
	Steward	4%	3%	2%
	Holder	80%	60%	40%
	Total	100%	100%	100%

Table 4.-- Variation in selected behavior class proportions by county, for two scenarios, for nonindustrial private forestland, North Coast Region.

		1990-2000		2000-2010	
	1980-1990	Scenario #1	Scenario #2	Scenario #1	Scenario #2
North Coast					
CAM3	6%	6%	17%	6%	28%
GROWER2	0%	2%	12%	3%	25%
Holder	80%	71%	60%	65%	40%
Humboldt County					
CAM3	7%	7%	18%	8%	29%
GROWER2	0%	4%	12%	5%	24%
Holder	79%	67%	60%	59%	40%
Sonoma County					
CAM3	4%	2%	15%	0%	27%
GROWER2	0%	2%	13%	4%	25%
Holder	89%	91%	67%	93%	45%

presented in table 5. Average harvest is greater under the second scenario, while inventory is lower. Growth is also lower until the later decades.

Wildlife Habitat

Results of a CALPLAN simulation also include acreage by county, owner, WHR cover type, and successional stage for the beginning year of each decade. The eight successional stages carried in CALPLAN are defined based on quadratic mean diameter (QMD) range and percent crown closure. Since the detail of the acreage data makes it difficult to analyze, Habitat Suitability Index (HSI) models are used to translate availability of the habitat structure into overall suitability for selected species.

In table 6, the approach is demonstrated for a single species, the fisher *(Martes pennanti)*. Each WHR type and successional stage has a unique suitability rating (0 to 1) for the fisher, based on feeding, breeding, and cover requirements. The fisher prefers dense stands of larger trees, with stage 8 being rated .93 out of a possible 1.0 rating.

Overall suitability is derived as the summation over all eight stages of the stage acreage times the stage HSI rating. For 1980-1990, the overall suitability rating is 573,000 habitat units.

Table 7 presents the initial and subsequent (year 2020) habitat structure on nonindustrial lands for the two scenarios. Under both scenarios, overall habitat suitability for the fisher increases, reflecting the buildup of inventory, especially in stages 6 and 8. The increase is greater under scenario 1.

CONCLUSION

The relatively simple, explicit methodology used in the FRRAP simulation approach is a positive step in assessment and policy analysis for a large, complex state such as California. It allows incorporation of different kinds of information from a

Table 5.-- Projected conifer inventory, annual average harvest, and average annual net growth, thousand board feet (MBF), for nonindustrial private forestlands, North Coast Region, for two different scenarios.

Period	Inventory (mbf)	Harvest (mbf)	Growth (mbf)
		Scenario #1	
1980-1990	14,733,880	96,404	326,311
1990-2000	16,914,432	148,816	355,020
2000-2010	19,028,016	156,431	372,945
2010-2020	21,464,000	133,006	403,688
2020-2030	24,469,728	115,396	445,862
2030-2040	27,819,024	125,373	464,767
2040-2050	31,446,896	104,316	490,497
		Scenario #2	
1980-1990	14,733,056	96,460	326,254
1990-2000	16,315,160	258,163	344,791
2000-2010	16,511,136	378,150	330,718
2010-2020	16,697,696	249,362	334,107
2020-2030	18,239,392	161,847	385,441
2030-2040	20,946,688	160,711	478,578
2040-2050	24,119,728	264,388	581,127

Table 6.-- Habitat Suitability Index (HSI), acres of habitat, and habitat units, by stage, for fisher *(Martes pennanti)*, nonindustrial private forestland, North Coast Region, 1980.

Stage	HSI rating	1,000 acres	1,000 habitat units
1	0.00	15	0
2	0.00	64	0
3	0.05	169	8
4	0.15	80	12
5	0.22	249	55
6	0.79	539	426
7	0.28	57	16
8	0.93	60	56
	Total	1,233	573

Table 7.-- Habitat units (in thousands) for fisher *(Martes pennanti)*, 1980-1990 and 2020-2030, for two scenarios, for nonindustrial private forestland, North Coast Region.

Stage	1980-1990	2020-2030 Scenario #1	2020-2030 Scenario #2
1	0	0	0
2	0	0	0
3	8	7	7
4	12	15	21
5	55	20	11
6	426	495	461
7	16	7	7
8	56	104	95
Total	573	648	602

wide variety of sources. The capabilities of the system will continue to improve as better information becomes available. For example, timber supply projections can be updated as additional information is received from Timber Harvest Plans, Board of Equalization harvest data, and various studies related to owner behavior and management practices. Serving as a central collection point for California resource management information, it also points to areas where existing data sources need to be improved or expanded.

The use of HSI models in conjunction with CALPLAN allows for some aggregate wildlife impact analysis, but is far from complete. Translating changes in total habitat units into impact on species populations is difficult at best. Future work of FRRAP will concentrate on generating separate estimates of total habitat units for feeding, breeding, and cover. This may allow better analysis for species where, for example, it is known that breeding habitat is the limiting factor.

Concentrating on acreages of potentially available habitat also neglects critical elements such as spatial considerations, species interactions, special habitat requirements such as snags or water, the effect of human intervention from recreation, roads, and rural housing, and effects of environmental contaminants. Although some data for these factors is available, for example the FRRAP GIS for spatial considerations, professional expertise will continue to play an important role in the absence of sufficient data and methods to simulate all these factors.

The simulation approach developed by FRRAP represents a unique approach to simulating future conditions for a wide variety of scenarios. The first scenario, based on the continuation of current trends, depicts only one of a number of possible futures for California. As such, it is not a hard or certain prediction of the future course of events, but is a simulation of what is likely to occur if the trends in the scenario do occur. Attempts to predict the future cannot be done with certainty, precisely because of the multitude of influences. The second scenario represents a different future for the state, reflecting a contrasting set of assumptions of future conditions. By using the scenario approach, forest policy can be effectively focused to take an active role in shaping future conditions in California.

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Alternative Specifications and Solutions of the Timber Management Portfolio Problem

Thomas A. Thomson and David C. Baumgartner

Abstract.--This paper studies several ways in which timber management portfolio problems can be specified and solved. Although portfolio analysis is very common for financial investments, and to some degree for agricultural investments, little work has been done in this area for timber management. Mills and Hoover (1982) solve a timber, agricultural, and financial securities portfolio using the MOTAD method of Hazell (1971). Thomson (1987) uses quadratic programming to solve timber management portfolios for the South and Midwest.

This paper uses the annual timber management returns for selected Midwestern and Southern species developed by Thomson (1987) to compare the following methods for solving timber management portfolios: (1) quadratic programming, (2) classical optimization, (3) MOTAD, (4) Sharpe's single-index model, (5) stochastic dominance, and (6) growth optimal portfolios. The underlying assumption for each alternative is that the timber species is managed in a fully regulated condition for producing sawtimber. All computer analysis was done on an MS-DOS computer.

Quadratic programming correctly solves the standard portfolio problem, and low cost microcomputer software will solve timber portfolio problems quickly. Classical optimization, although straightforward, does not appear to be well suited for timber portfolios as negative portfolio weights are common, and there are no secondary markets for timber investments. Although the solution method can be adjusted when negative portfolio weights appear, it is easiest to use another solution method. The MOTAD linear approximation method appears to work quite well and is a useful alternative when quadratic programming software is unavailable. The single-index model is another approximation technique developed to relieve the computational burden of solving large portfolio problems. For the small problems encountered in timber management portfolios, it is easier to solve a quadratic program than to perform the necessary regressions for the single-index technique. A side benefit of using the single-index approach, however, is that the estimated betas are a good measure of the relative riskiness of an investment.

[1]*Research Forest Economist, North Central Forest Experiment Station, 1407 S. Harrison Road, East Lansing, MI 48823.*

To respond to criticisms of the standard portfolio analysis, we also analyze the stochastic efficiency and optimal growth properties of the portfolios. All of the portfolios were found to be second degree stochastically efficient, thus the standard mean-variance analysis appears to yield stochastically efficient results. In analyzing the long run returns that can be expected on the portfolios we found that expected long run returns lower than expected single period returns, and that maximizing expected single period return does not maximize long run return. Risk aversion in the short run is required to maximize long run returns.

Introduction

Since the pioneering work of Markowitz (1952), portfolio analysis has become a standard part of many financial decisions. Its basic premise has long been known, that is, don't put all of your eggs into one basket. Markowitz formalized the problem as minimizing the variance (or standard deviation) for any level of expected return. This was called efficient investing. A key finding of this work was that investments that may appear undesirable on their own (too risky given its expected return), may be valuable components of a portfolio of investments. Investments with rates of return that have little correlation with rates of return of other investments provide low portfolio risk. Economics and financial literature has established much knowledge on the subtleties of risk-return efficient investing including assessment of investors feelings toward risk, the statistical distributions of rates of return, and the market equilibrium outcomes when investors optimally diversify their holdings.

The forestry literature also has recognized risk in forest management for some time. Much of the earlier work has centered on the uncertainty associated with forest inventory sampling (Arvanitus and O'Regan 1967, Hamilton 1970). Financial uncertainty of timber management, however, has also been studied. Dowdle (1962) framed Markowitz's idea for evaluating timber investments and applied this to a trade-off between the present net worth per tree at rotation and its variance. Marty (1964) proposed using dominance criteria for selecting timber management alternatives under risk.

Mills and Hoover (1982) used portfolio analysis to determine whether it was rational for Indiana farmers to include timber investments in their land use and financial portfolios. Although the rates of return from timber investments were lower than those of agricultural investments, the lack of correlation between these investments allowed both to be included in some efficient investment portfolios. Thomson (1987) included portfolio analysis in his comparisons of the financial risks of timber growing between the South and Midwest.

In addition to the applications of using portfolio analysis to determine the desirability of including various timber components for portfolios, we also feel that this approach might be used to develop measures of relative risk based upon variations in the rates of return for alternative forestry investments. These alternatives might include buying forest land, planting or improving certain tree species, developing genetically improved trees, thinning, pruning, fertilizing, or growing mixes of pulpwood, sawtimber, or veneer logs on one or more sites. Variation in returns could in itself provide a summary measure of risk for alternative forestry investments and could be used to develop an efficient portfolio of forestry investments which would minimize risk for given rates of return. Further investigation of its use in this context is warranted.

The standard approach for solving efficient portfolio frontiers for this paper is quadratic programming as was used by Thomson (1987). Another approach uses the classical optimization technique of Lagrangian multipliers. The MOTAD approach of Hazell (1971) is another alternative. Single-index methods (Sharpe 1963) have been suggested as an easier approach to estimating the efficient portfolio. Collins and Barry (1986) have suggested using the single-index model to determine efficient farm management portfolios. The use of stochastic dominance has been proposed as an alternative to mean-variance portfolio choice. Bawa (1982) summarizes a number of examples the financial economics literature and Anderson et al. (1977) give examples from agricultural economics. Grauer and Hakansson (1986) suggest that the appropriate portfolio selection focus is long run risk and return, rather than single period risk and return.

Given this variety of ways to approach portfolio problems, our paper compares these methods for developing timber management portfolios. It develops the efficient risk-return trade-off each one proposes, compares the difference in solution methods, and describes under what circumstances each may be a viable alternative for solving timber management portfolios.

The Data

Thomson (1987) derived a data set to solve the questions posed concerning financial risk between the Midwestern and Southern timber management portfolios. Because of the time consuming nature of developing the periodic returns to timber management, and because the focus of this paper is to compare among several methods of solutions with the same data set, we decided to use that data set for the analysis presented here. The data for calculating efficient portfolios consists of period by period rates of return for each timber management investment being considered. The investments considered in this paper are fully regulated sawtimber producing forests of the several species. Midwestern species include red pine, white pine, aspen, and red oak. Southern species include southern pine, ashes, gums, and oaks. The annual rate of return for each species was calculated as shown in Thomson (1987):

$$R_t = [(P_tG + P_tH - C)/P_{t-1}G] - 1$$

where:

Pt = stumpage price in period t,

H = Volume harvested annually from the fully regulated forest,

G = growing stock index, which is constant from period to period for a fully regulated forest,

C = the annual cost of managing the forest.

Combining price, growth and yield, and management costs information, one can calculate the periodic return for any given fully regulated forest. P_tG is the current value of the forest growing stock (like the price of a stock). $P_{t-1}G$ is last years value of the forest growing stock (like last years stock price). The monetary dividend the forest has paid is the value of the harvest, P_tH, minus the annual forest management costs.

Growth and yield information and forest management strategies and costs were garnered from a variety of sources as noted in Thomson (1987). Annual sawlog stumpage price data from 1960-1980 for pine, ash, oak, and gums in Louisiana was found in Ulrich (1985). Lothner et al. (1982) provided similar data for white pine, red pine, aspen, and red oak in Minnesota. All price and cost data was converted to real dollars, thus, all rates of return reported here are real rates.

Analysis

The objective for most of these techniques is to minimize the level of risk for any expected return. The risk of a portfolio is usually measured as its standard deviation (or variance). The constraint on the portfolio is that the sum of the individual investment alternatives must sum to the total portfolio which is generally normalized at one. To trace out the individual points of the efficient frontier requires that one vary the expected return on the portfolio from the minimum variance rate of return

through the rate of return on the investment with the highest expected rate of return. The portfolio problem may be formally stated as (Francis and Archer 1979):

$$\text{Minimize} \quad \sum_{i}\sum_{j} X_i X_j \sigma_{ij}$$

$$\text{subject to:} \quad \sum_{i} X_i E(R_i) >= R^*$$

$$\sum_{i} X_i = 1$$

where X_i's are the portfolio weights, σ_{ij} is the covariance between investment i and j, and $E(R_i)$ is the expected return from investment i. The objective is to minimize the risk (defined as variance of returns), subject to earning a given level of return (R^*), while requiring that the portfolio weights sum to 1 (full investment in the given alternatives). All computing was done on an MS-DOS microcomputer.

Quadratic Programming

Where non-negative portfolio weights are required, the standard portfolio problem can be solved using quadratic programming. From the returns calculated in each period over the sample period, the mean return and the variance for each timber investment was calculated, as was the covariance for each pair of investments. The minimization of variance is the quadratic object function subject to the linear constraints of having the portfolio weights add up to one, and the portfolio return equal a set level. After setting up the inputs, the expected return was varied parametrically to trace out the efficient frontier. The solutions were derived using the QPROG software (Saigal 1986). Figure 1 shows the efficient portfolios frontier in mean-standard deviation space for our data set. This result, also found in Thomson (1987), will be referred to as the standard analysis in this paper. Table 1 shows timber investment weights for the minimum risk portfolios with an expected return of 6, 7, 8 and 9 percent.

Classical Optimization

Classical optimization solves the portfolio problem presented above by setting the problem in the Lagrangian format (Francis and Archer 1979). Taking first derivatives of the series of equations yields a system of linear equations that can be solved using matrix algebra. The portfolio rate of return is varied and the system resolved to trace out the efficient frontier. The mathematical calculations were done using the matrix routines of the Smart Spreadsheet[2] (Innovative Software 1986). The frontier developed using classical optimization is shown on figure 1.

[2]*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of*

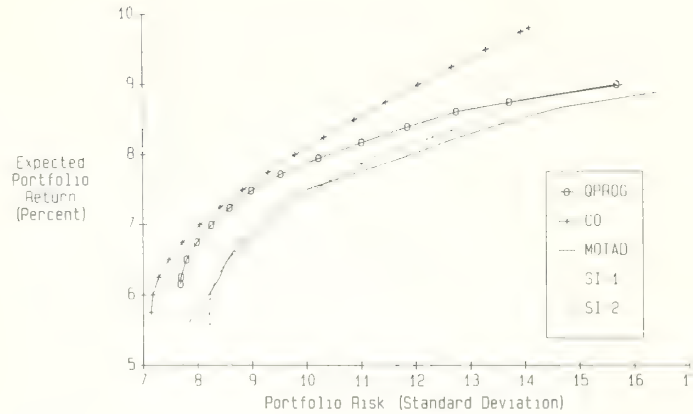

Figure 1.--Expected portfolio return (percent) versus portfolio risk (standard deviation) calculated by the standard analysis (QPROG), classical optimization (CO), MOTAD method (MOTAD), Sharpe's diagonal method (SI-1), and Elton and Gruber's covariance approximation (SI-2).

Figure 1 shows that the frontier developed by classical optimization has a higher rate of return for any level of risk than the standard analysis discussed above. This result is expected as this is the least constrained approach to portfolio analysis. By analyzing the portfolio compositions (see table 1), however, one will see that all portfolios calculated by this method contain negative weights. In other words, some of the investments (say in southern pine or gum) are financed through having negative weights in other investments (such as red pine and southern oak). Foresters know, however, it is impossible to have negative red pine forests. To have negative red pine investments would require financial markets in such forests that would allow "short selling," that is selling of a security one does not own and investing the proceeds in another security. It is unlikely that financial markets in this sense will arise in timber investments so a portfolio which contains negative investments is not realistic. Classical optimization is a good technique for solving portfolio problems when negative portfolios do not enter the optimal solution, or for those investments where selling short is an alternative. For timber portfolios it appears inappropriate due to negative weights which are unlikely to be realizable in timber investments.

MOTAD (Minimization of Total Absolute Deviations)

Linear programs are an efficient method of solving a constrained set of equations and typically do not allow negative decision variables. The use of linear programs is wide spread, as is the availability of computer solving routines making it seem an attractive alternative for solving portfolio problems. The objective of minimizing portfolio variance, however, is non-linear. Hazell's (1971) MOTAD method replaces the objective of minimizing the variance, with the linear objective of minimizing of the absolute deviations from the mean. While this is a less efficient method of minimizing deviations (compared to

Table 1.-- Portfolio weights of various species to yield rates of return of 6, 7, 8, and 9 percent at minimum risk calculated by the standard analysis (QPROG), using classical optimization (CO), using the MOTAD method (MOTAD), using Sharpe's diagonal single-index model (SI-1), and using Elton and Gruber's variance-covariance estimation technique (SI-2).

Species	QPROG	CO	MOTAD	SI-1	SI-2
-For 6 percent expected return-					
Red pine		-0.178			
White pine		0.066			
Aspen	0.138	0.150	0.114	0.067	0.080
Red oak	0.081	0.101	0.002	0.032	0.038
So pine	0.236	0.348	0.220	0.171	0.165
Ash		0.077		0.092	0.120
Gum	0.545	0.761	0.664	0.307	0.270
So oak		-0.325		0.331	0.326
-For 7 percent expected return-					
Red pine		-0.184			
White pine		0.075			
Aspen	0.127	0.153	0.097	0.043	0.051
Red oak	0.078	0.100		0.025	0.029
So pine	0.445	0.533	0.391	0.433	0.433
Ash	0.242	0.334	0.317	0.179	0.189
Gum	0.108	0.653	0.196	0.165	0.154
So oak		-0.664		0.155	0.145
-For 8 percent expected return-					
Red pine		-0.190	0.097		
White pine	0.053	0.083			
Aspen	0.047	0.156	0.016	0.016	0.019
Red oak	0.055	0.099		0.017	0.018
So pine	0.697	0.718	0.501	0.698	0.704
Ash	0.148	0.591	0.386	0.261	0.254
Gum		0.544		0.007	0.005
So oak		-1.002			
-For 9 percent expected return-					
Red pine		-0.195	0.347	0.026	0.020
White pine	0.347	0.091		0.329	0.334
Aspen		0.159			
Red oak		0.098			
So pine	0.653	0.904	0.653	0.645	0.647
Ash		0.847			
Gum		0.436			
So Oak		-1.340			

using the variance) it appears to have successfully solved many problems to which it has been applied (e.g., Mills and Hoover 1982). In place of the variance-covariance matrix, one uses a matrix of deviations from the mean for each data period. This data was set up using the Smart Spreadsheet, which was then written into a Data Interchange Format (DIF) which was read in to the Kinetics Linear Programming System[2] (Kinetics Software 1984) for solving the problem. The required rate of return was varied parametrically to trace out the efficient frontier.

Typically when using the MOTAD method, one would trace out the efficient frontier in mean-absolute deviation space, rather than mean-standard deviation space. To present consistent results in this paper, however, we used the portfolio weights determined from the MOTAD solutions along with the full variance-covariance matrix to calculate the true portfolio variance which would result from these weights. It is these values that are shown as the MOTAD portfolios and plotted on figure 1. Comparing the MOTAD results to the quadratic programming results shows that MOTAD gives a reasonably close approximation of the minimum risk portfolios. Results of usefulness of MOTAD depend on how closely it tracks to the QPROG solution. It is certainly easier to do the MOTAD calculations as one does not need to compute a variance-covariance matrix. For those who have familiarity or availability of only linear programming computer codes, it serves as a good approximations tool. With the availability of microcomputer quadratic programming code, however, it may be worthwhile to choose the quadratic programming solution.

Sharpe's Single-Index Model

To use either classical optimization or quadratic programming requires the variance-covariance matrix for the investments being considered. When choosing among a large variety of investments calculation of this matrix can be difficult. The single-index model overcomes the difficulty of calculating the variance-covariance matrix by using linear regressions on an index to estimate appropriate values for the variance-covariance matrix.

Sharpe (1963) showed his single-index could be applied at very low cost, relative to the standard quadratic programming codes available then. Moreover, he found that the relatively few parameters used by the model led to very nearly the same results obtained with larger sets of relationships among securities, and that the low cost model provided an attractive candidate for initial practical applications of the Markowitz technique. Sharpe maintained that the "diagonal" or single-index model had two virtues: "it is one of the simplest that can be constructed without assuming away the interrelationships among securities,and there is considerable evidence that it can capture a large part of such interrelationships." The major assumption of the model is that the returns of various securities are related only through common relationships with some basic underlying factor. The return from any security is determined solely by random factors and this single factor.

Collins and Barry (1986) employ the single-index model using expected returns from 12 crops grown in the Imperial Valley of California. They defined the aggregate variable (the index) as an unweighted average of the returns on the 12 crops over a 17-year period. The single-index Betas and the expected returns provided the input data for deriving risk efficient crop

combinations which closely approximated those derived with a full variance-covariance matrix. We performed a similar analysis with the timber management returns using the unweighted average price of all timber species to calculate annual percent changes in average price which we used as our index. We used the diagonal covariance matrix technique and QPROG to determine risk minimizing portfolio weights for a given rate of return. We then took those portfolio weights and calculated the true portfolio variance using the full variance-covariance matrix. This result is presented as SI-1, on figure 1 and in table 1.

Elton and Gruber (1981) suggest an alternative approach to estimating the single-index model which also simplifies the estimation of the covariances. From the regressions performed for the above model, one can estimate the covariance of investment i, and j, as their Beta estimates times the variance of the market. We also used this approach for estimating the variance-covariance matrix and solved the portfolio problem using QPROG. From the resultant portfolio weights, we calculated the true portfolio variance using the full variance-covariance matrix. This result is presented as SI-2, on figure 1 and in table 1.

Either single-index model gave reasonably good results in predicting the true efficient frontier. Better results might be garnered through use of a superior index, or through use of multiple indices. At higher risk levels, they closely approximate the standard frontier. For the small problems that are typically analyzed as timber management portfolios (small number of candidate species), there is little difficulty in estimating the variance-covariance matrix using microcomputers. It is more time consuming to run the series of regressions for the single-index model than to calculate covariances thus the portfolio calculation is better left to the standard method.

Sharpe (1963) was primarily concerned with reducing the computational burden of including a large number of securities in a financial portfolio. Collins and Barry (1986) employed this approach to reduce the complexity of portfolio analysis to that within the capabilities of farm operators or advisors using 8 bit microcomputers to develop efficient portfolios for a relatively few crop production alternatives. Although their primary concerns have been alleviated by the current availability of efficient quadratic programming techniques, and more advanced microcomputers, our analysis of the single-index model led to several insights to explicit consideration of risk in forestry investment decisions.

Thomson (1987) found that Betas derived from regressing the returns to his eight forestry investments on the Standard and Poors Composite Index returns were not significant (table 2). This result suggests all timber investments have low market risks. Selecting among timber investments, however, Thomson addressed through portfolio analysis. Performing the regressions on an index which would yield statistically significant Betas will produce a measure of the relative riskiness of the various timber management investments. We found that Betas based on his return data and the average of price returns as a single-index were significant and gave an indicator of the

Table 2.-- Mean returns, standard deviations, betas, t values, and R squares for the standard and poors composite index and selected timber growing investments, regressed against this index.

Location	Species	Mean return	Standard deviation	Beta	t statistic	R squared
New York	S&P 500	0.0311	0.1167	1.00		1.00
Midwest	Red pine	0.0951	0.3002	-0.69	-1.34	0.09
Midwest	White pine	0.0981	0.2955	-0.91	-1.87	0.16
Midwest	Aspen	0.0367	0.2912	-0.47	-0.91	0.04
Midwest	Red oak	0.0553	0.2973	-0.49	-0.94	0.05
South	Pine	0.0857	0.1365	-0.07	-0.28	0.00
South	Ash	0.0698	0.1277	-0.14	-0.64	0.02
South	Gums	0.0555	0.1000	-0.07	-0.39	0.01
South	Oaks	0.0534	0.0976	-0.12	-0.72	0.03

variability and relative risk of his alternative forestry investments. Table 3 presents the results of the single-index regressions. The high Betas for white and red pine suggest these timber investments are relatively risky. The negative and non-significant beta for aspen shows it is the least risky. The portfolio weights shown in table 1 show how red and white pine enter only the riskiest portfolios, and that aspen enters the more risk free portfolios.

To further simplify the analysis of risk in timber management investments, we investigate the effect simply considering the price variation rather than the returns variation. Price variation can be analyzed by simply obtaining price series data rather than using the more involved analysis of constructing normal forests and determining the return from managing them. A series of returns of the form:

$$R_t = (P_t/P_{t-1}) - 1$$

was used as the dependent variable in regressions against the average price index described above. The results of these regressions are presented in table 4.

Table 3.-- Mean returns, standard deviations, betas, t values, and R squares for average annual price changes (the index) and timber management returns from selected timber growing investments regressed against this index.

Location	Species	Mean return	Standard deviation	Beta	t statistic	R squared
Both	Index	0.0336	0.1167	1.00		1.00
Midwest	Red pine	0.0951	0.3002	2.25	7.62	0.76
Midwest	White pine	0.0981	0.2955	2.14	6.69	0.71
Midwest	Aspen	0.0367	0.2912	-0.09	-0.16	0.00
Midwest	Red oak	0.0553	0.2973	0.44	0.75	0.03
South	Pine	0.0857	0.1365	0.82	4.13	0.49
South	Ash	0.0698	0.1277	0.83	4.91	0.57
South	Gum	0.0555	0.1000	0.58	3.94	0.46
South	Oaks	0.0534	0.0976	0.55	3.66	0.43

Table 4.-- Mean returns, standard deviations, betas, t values, and R squares for average annual price changes (the index) and annual price changes of selected timber species.

Location	Species	Mean return	Standard deviation	Beta	t statistic	R squared
Both	Index	0.0336	0.1167	1.00		1.00
Midwest	Red pine	0.0514	0.2864	2.15	7.66	0.77
Midwest	White pine	0.0542	0.2819	2.04	6.73	0.72
Midwest	Aspen	0.0364	0.2832	-0.07	-0.13	0.00
Midwest	Red oak	0.0516	0.2890	0.44	0.76	0.03
South	Pine	0.0471	0.1277	0.76	4.11	0.48
South	Ash	0.0394	0.1235	0.79	4.70	0.55
South	Gum	0.0292	0.0969	0.55	3.74	0.44
South	Oaks	0.0326	0.0947	0.51	3.47	0.40

The beta values in table 4 closely correspond to the beta values of table 3, suggesting that the simple technique of using returns estimated from price variation will give insights into the relative riskiness of various timber investments. Several good time series of prices for various tree species and products are available. Price variations regressed on an appropriate single-index can provide initial estimates of risk relative to returns for a wide range of timber investments.

Stochastic Dominance

One of the criticisms of mean-variance portfolio analysis is that a mean-variance efficient portfolio could be dominated by some other portfolio. A rational decision maker would never choose a dominated portfolio, although the mean-variance portfolio analysis might indicate either as acceptable. Individual investment opportunities can be evaluated as can portfolios to determine whether they are stochastically efficient dominated.

Several levels of stochastic efficiency have been proposed (Bawa 1975). First degree stochastic efficiency, or absolute dominance as it is also called, is a formalization of the dominance criteria proposed for timber investments by Marty (1964). The basic criteria for first degree stochastic dominance is that more is preferred to less so a first evaluation on investments is to compare their expected values. An investment with a given expected value can never dominate an investment with a higher expected value, although it might also not dominate an investment with a lower expected value. For absolute dominance, the dominating asset must also have a return that is greater under all states of nature.

Because few investments are absolutely dominated, other less restrictive measures of dominance have been applied. Second degree stochastic dominance adds the criteria of risk aversion to that of more being preferred to less. Risk aversion is a part of the implicit criteria of portfolio analysis, for if investors were risk neutral, the investment with the highest expected rate of return would always be chosen. Second degree stochastic dominance (SSD) requires that the area under the integral over expected return of the dominating probability distribution be less than or equal to the area under the other distribution at all points (see Bawa 1975). Pair-wise comparisons are made among investments to determine if some are dominated. As noted by Anderson et al. (1977), a first pass at these comparisons can be made by looking at the lowest observed return for each investment. If the portfolio with the higher mean also has a probability of a lower return, it cannot SSD dominate the investment with the lower expected return. When this test fails, then a more complete pair-wise comparison must be made. We looked at the lowest observed return for each of the portfolios calculated for the standard analysis and found that as the means increased, the lowest returns decreased showing that all points tested on the efficient frontier were also SSD efficient. As a result we did not have to resort to the more robust method of pair-wise comparison of all portfolio distributions. From this test it appears that timber portfolios which are mean-variance efficient will also be SSD efficient.

Growth Optimal Portfolios

Another criticism of the standard portfolio problem solved above is that it maximizes the expected single period return for any desired level of risk. Most investors, however, can be expected to focus more on long term wealth accumulation than on single period gains. Grauer and Hakansson (1986) present a method to develop portfolios that maximize the expected long run wealth gains for various levels of investor risk tolerance. To respond to the issue raised by Grauer and Hakansson, we model the long run expected return and variance for the standard portfolio frontier developed above. We employ a stochastic simulation technique. Grauer and Hakansson by contrast use a non-linear optimization method.

The essence of the long run problem is this. If one chooses a given portfolio and holds it for a long time, what is the expected rate of return and variance for that portfolio over the long haul. Binkley (1981) has shown that the long run variance for a given investment will be much lower than its single period variance. What is less apparent though, is that long run rates of return may be lower than the expected single period rate of return. In this situation, long term wealth accumulation may be higher from less risky portfolios or in other words, risk aversion in the short run can lead to higher long term wealth accumulation.

The simulation model used in this portion of the study assembled the returns to each portfolio of investments for each period, and assumed this was the true distribution of returns. Each observed return was assumed equally likely to occur in any year in the future. The relative wealth change (1 plus the annual rate of return) one would have at each period in the future was then simulated through randomly choosing an example year's return, and calculating the value of ones portfolio at the end of that year. This process was continued for 50 years (the long run). The relative annual wealth changes each period were multiplied

together to calculate the terminal period wealth (relative wealth in year 50). The internal rate of return for the 50 year period was then calculated as:

$$(W_{50})^{1/50} - 1$$

where W_{50} = relative wealth at year 50. Relative wealth at year 1 is one.

This simulation calculates a single long run rate of return for each portfolio. To generate the long run return distribution for each portfolio, this process was run 500 times. For each portfolio, 500 long run internal rates of return were calculated. The mean internal rate of return and its standard deviation were calculated and the results are plotted on figure 2, along with the standard single period risk efficient frontier. Figure 2 shows how the long term risk is much lower than the single period risk. To emphasize the comparison of long run to single period expected rate of return, figure 3 plots these two curves again, but both are plotted over single period standard deviation. Figure 3 graphically shows that the most risky portfolio, that is the one with the highest return and highest risk in the short run, remains the riskiest portfolio, but its long run return is lower than some less risky portfolios and is in that sense dominated. The turn down (increasing risk with decreasing return) occurs at the point where the single period standard deviation equals 16.5 percent. Because timber investments of the kind envisioned in this paper (management of fully regulated forests) are of a long term nature, it seems wise to consider only investments that are non-dominated in the long run, that is portfolios with a short run standard deviation of 16.5 percent or less. If timber investors expect to hold timber investments over the long term, then emphasis should be on the long run rather than single period risk-return trade-offs.

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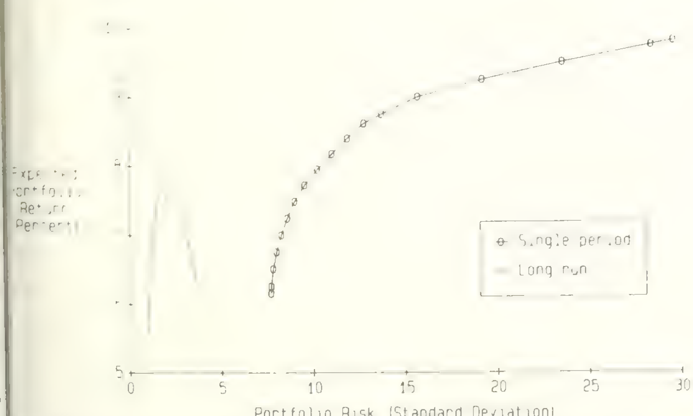

Figure 2.--Expected portfolio return (percent) versus portfolio risk (standard deviation) for the standard analysis (single period), and long run analysis (long run).

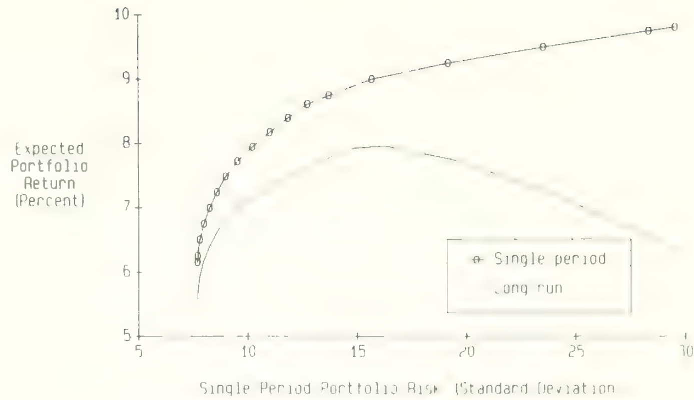

Figure 3.--Expected portfolio return (percent) versus single period portfolio risk (standard deviation) for the standard analysis (single periods), and long run analysis (long run).

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Area Based Forest Planning

William J. Connelly[1]

Abstract.--This paper proposes an alternative framework for National Forest Planning, analysis, and program implementation. A more systematic approach based on area specific data and analyses is presented in contrast to the current reliance on Forestwide linear programming models.

At present National Forest planning and program implementation are being managed as two separate processes. While a need for integrating Forest planning with project planning is recognized, there are few procedures in place to achieve this. Further, there has been limited attention to completing the cycle of Forest planning, where Forest Plans are both implemented and reevaluated at the Field level.

One possible solution to this problem is Area Based Forest Planning, where implementation of Forest Plans is evaluated for particular areas. This area evaluation serves both to identify projects for implementing Forest Plans and to provide new options for future Forest Plans. This type of Planning would involve simpler analysis models, but wider use of analytical tools at both the Forest and District level. While Area Based Forest Planning in this paper is directed towards National Forests, it would also be applicable to other public and private forest land managers.

The Planning Problem

Although there has always been a certain degree of Forest Planning prior to the passage of the National Forest Management Act (NFMA) of 1976, planning was usually either programmatic (timber sale planning) or area specific (planning for the development of a downhill ski resort). Both of these actions can be classified as "Incremental Planning" (Lindbloom 1965). Generally, "Incremental Planning" focuses on small changes in land management where a particular need arises. In the case of timber sale planning, the increment being considered is whether or not to prepare a timber sale for a particular sale planning area. The increment for the ski area is whether or not to prepare for development, and if so of what nature. The benefit of incremental planning is an effort focused on the particular decision being considered. The drawback is limited consideration of issues or resources beyond the immediate scope of the decision itself.

[1]*Umpqua National Forest, Roseburg, Oregon.*

With the passage of NFMA, National Forest Planning made a significant change in the major thrust of its planning. In order to develop a true multiple resource management plan, the reliance on incremental decisions was abandoned for the more predominant "rational comprehensive" planning model. With this model, the Land Management Plans prepared by each National Forest would derive from a series of integrated land and resource management alternatives for the entire forest. By weighing the different management options presented in these alternatives along with public comment, the Regional Forester is able to identify the single alternative that best "maximizes net public benefits in an environmentally sound manner." The final land management plan would contain detailed standards and guidelines for the implementation of the selected alternative.

While the comprehensive Forest Plan presents a detailed structure for managing a National Forest, it is not detailed or focused enough to provide very specific implementation direction for either particular areas or particular programs. Exceptions to its direction are inevitable. If it does provide very specific direction, it runs the risk of being resisted by Field personnel who have had limited involvement in its development. There is a fear that detailed plan direction will be used in the future by appellants to obstruct particular Forest projects, including those which are in the "spirit" of the plan. A related problem is that while the Forest Plans are being developed, incremental planning has been continuous; sometimes making decisions which compromise alternatives under consideration in the comprehensive plan. When a final plan is finally established, a difficult transition period is likely to occur. Its difficulty is probably proportional to the severity of changes from current direction and the amount of detailed standards and guidelines in the Plan.

Even though the Forest Service is now clearly committed to both comprehensive and incremental or project planning, the capability and commitment to properly integrate the two has not been realized. This is most vividly demonstrated by the present nature of Forest Planning organizations. Most Planning organizations are located solely at the Supervisor's Office with their efforts focused on the comprehensive plan. There is little or no planning organization at the District level where most of the project planning takes place. Nationally, funding for Planning and Information Management is not recognized in budget line items approved by Congress; Planning either "begs" or "steals" from other functional areas for funding. There is a separation not only in philosophy, but in the organization itself between comprehensive and incremental planning.

The Modeling Problem

The current planning effort centers around the required comprehensive planning model: FORPLAN (Johnson 1986, Johnson et al. 1986) for this round of planning. FORPLAN's structure essentially focuses on timber management options with their resulting environmental and economic consequences on a single acre of land. When dealing with more than one acre of land under the same timber management options; simply multiply by the number of acres under the same treatment. The combination of these management options called "prescriptions" matched with units of land of similar responsiveness called "analysis areas" forms the linear programming problem to be solved by FORPLAN.

Other resource considerations and management activities can be represented in the FORPLAN model if their production functions or work needs can be represented in an appropriate per acre structure. Of course, this results in an expansion of model size by further delineating analysis areas, expanding the prescription set, and increasing the number of constraints. Prescriptions which blend timber management with other resource objectives further expand model size by increasing the number of timing choices. This tends to discourage the development of such multi-resource prescriptions.

The other significant problem in FORPLAN's structure has been frequently called the spatial problem. Until recently, FORPLAN was unable to recognize spatial relationships between adjacent areas of land. This left an analyst with limited options if spatial relationships were important in the model structure. The analyst could use an analysis area parameter to distinguish spatial units, further subdividing the analysis areas and increasing model complexity. To deal with this problem, "aggregate emphasis" (Version 1 FORPLAN) or "coordinated allocation zones" (Version 2 FORPLAN) were provided to represent integrated management choices on particular spatial units. While the analyst could define such choices, he had a limited ability to control the activity and output schedule of the choice. These area capabilities do not replace the normal per acre relationships, but, rather, are an additional structure to it.

Contrary to the structure of FORPLAN and most other per acre timber harvest scheduling models, most production relationships of the Forest are not per acre based. Recreation use is most certainly not related to acreage, or even acreage of particular R.O.S. (Recreation Opportunity Spectrum) classes. The dominant modeling technique for recreation has focused on providing for a certain capacity of recreation classes, presented as a per acre carrying capacity. If there is sufficient total capacity in that class, there is no recreation problem, regardless of whether or not the area has any qualities which would make recreationists want to recreate there. The per acre formulation of FORPLAN leads to a largely irrelevant analysis regarding recreation demands and supply.

Similarly, wildlife problems require consideration of spatial relationships due to the inherent territoriality of wildlife itself. Big game habitat involves a subtle interaction between forage and cover relationships. While both forage and cover can be modeled on a per acre basis, the interrelationship of the two components together can only be achieved through the use of constraints. Other wildlife habitat requirements often depend on a mixture of habitat being present in particular locations. Most of the focus on maintaining viable populations of wildlife species has shifted away from the amount of habitat, as represented in acres, to the distribution of those habitats and other disturbances within the range of a species. Constraints are used in Forplan to try to control these relationships, but there are not enough to manage the spatial considerations of wildlife and also meet all other objectives. Even with constraints, FORPLAN models will always seek the solution which best fulfills its objective function, often leading to an unintended solution for the wildlife problem.

One final example are transportation problems. There are few analysts who have not struggled to represent roading problems with FORPLAN, only to discover that there is no appropriate way to properly integrate roading activity schedules with timber harvest schedules on a forestwide basis. Network problems, such as roading, traffic management, or sediment loads, require a reasonably site specific analysis in order to relate the activity on the network to ongoing activity in related spatial units. Other models such as IRPM (Kirby et al. 1980), Transhipment (Kirby et al. 1981), and recent enhancements to FORPLAN version 2 deal with such network problems on a local area basis, but cannot address an entire forest.

At the Field level, there are a variety of computer aids and a few models such as IRPM or FORPLAN being used with increasing frequency for incremental planning problems at the District level. Geographic Information Systems (GIS) to the extent that they are available, maintained, and used are usually the first reference in preparing project level plans. A variety of new tools are being considered at the District level. These tools can serve both as an aid to project planning, and as a source of information for monitoring and evaluating the Forest Plan. Increasingly, there is discussion and implementation of area planning concepts at the District Level. This is often matched by

a concern about creating another level of planning, with an expectation of "Area Plans" being tied up in the same kind of problems which have affected Forest Plans.

Area Based Forest Planning

Whether a Forest Plan has provided detailed direction for a particular sub-area of the Forest or not, the need is being increasingly recognized for an additional level of comprehensive planning below the Forest level. The primary impetus for this probably comes from Engineering organizations which have found that the Forplan model and Forest Plans do not provide significant assistance in solving their problems and may instead compound their problems by providing inappropriate information. But many other functional areas are also realizing that adequate achievement of their objectives will depend on another level of comprehensive planning. Incremental project planning without some additional comprehensive considerations will be inadequate.

On other hand, Area Planning which proceeds in the same basic environment as project planning may resolve a few problems for a particular area, but does not provide adequate feedback into the Forest Planning process. Area planning, no matter how detailed, may count for little in either this or future rounds of Forest planning, if there are no mechanisms in place to integrate the data developed from area plans into both current and future Forest Plans. Let's examine how Area Planning and Forest Planning could work together to achieve both comprehensive and incremental planning objectives.

Area Determination

Obviously, the first step will be to define Planning Areas. This initial definition can be a serious problem and deserves careful consideration at both the Forest and District level. The most important aspect of area definition is that the areas be large enough to address a number of the cumulative issues affecting an area, yet not so large as to be unable to recognize individual spatial activity decisions (i.e,. harvest units, specific roads, specific trails, specific winter range forage and cover areas, specific range allotments, etc.). It would also be desirable to create an area structure related to the structure of the Forest Plan. While functional areas are likely to conflict over the parameters to use in area definition, the parameters are not that important, as long as the area boundaries are not used as boundaries to the analysis. In order to maintain linkage to other area analyses and forest level planning, it is essential that the areas be fixed for the planning period covered by the Forest Plan.

Inventories

Once areas have been defined and an analysis of a particular area begins, the first step is usually the collection of inventory information. Most of this information can be provided by data in a GIS system. The success and efficiency of this first step in the analysis will depend on how well the GIS and other related data is maintained. In addition, some Field study of the Area will also be required to identify new information and verify GIS data.

From this initial inventory phase, a considerable amount of information should be assembled. With an efficient GIS, multiple map overlays and statistical information can be produced to create a clearer picture of Area. The inventory phase should produce site specific information on such questions as vegetative character of the land, soil conditions, mineral availability, the condition of timber stands, range forage, wildlife populations, unique wildlife habitats, the condition of watersheds and riparian habitat, and special features from a recreational standpoint. In addition, existing uses would also be recognized such as range allotments, mining activity, timber and silvicultural activity, roads, trails, and campgrounds. The inventory should be comprehensive, even if it must be superficial in some areas.

Scoping

The relative emphasis on a particular aspects of the inventory will probably be proportional its importance in the area's management. Each area analysis will also need to establish priorities for itself and its eventual decision making. This process has been called "scoping." It would involve reviewing the current plan direction, identifying new and emerging issues, meeting minimum legal and policy requirements, recognizing interrelated commitments or problems with adjacent areas or ownerships, and identifying other special problems. In some cases, overlapping problems may suggest enlarging the area to be analyzed, by focusing on two areas where an interrelated action is being contemplated. This scoping may or may not involve public involvement. It is important that future new management opportunities be identified, even if they conflict with current plan direction, current use of the area, or even minimum legal requirements.

Alternative Development

From the scoping process, a variety of management opportunities for the area can be developed. These opportunities can be organized into alternative management programs for the areas. Two basic kinds of alternatives need to be developed in the process in order to not only manage the area for the plan period, but also to identify area management opportunities for the future.

The broader type of alternative is the "planning alternative." Each of these alternatives has a set of specific objectives and activity schedules for an area. Each presents a different mix of activities, outputs, and environmental effects as a result of the land management objectives and activity schedule. These alternatives include activity schedules beyond the plan period with

a reasonably detailed estimation of the environmental consequences and activity costs in outyear periods. These "planning alternatives" should not be bound by current management direction for the area. It is important to develop a large number of alternatives, each with a slightly different mix of objectives and schedules. An inadequate set of alternatives will limit the future opportunity of the forest to develop efficient or issue responsive alternatives in the Forest Planning phase.

The other type of alternative is the "action alternative." The "action alternative" is focused on identifying a series of management objectives and activities for the plan period. The focus of "action alternatives" would be on plan period actions and objectives such as which acres to harvest, what roads should be built, what recreation opportunities should be provided, and what areas should be managed for snag habitat, big game cover, or big game forage. As such the "action alternative" must meet minimum legal requirements, be consistent with Plan direction for the Area, and recognize current uses of the land. These alternatives are focused on implementation actions in order to achieve current management objectives.

Both types of alternatives are linked together as each depends on the other. In order to define the actions for the planning period, there will also need to be an identification of likely future consequences and the management options which will remain for the future. These options or "planning alternatives" for an area will only be useful in future planning, if the option for their implementation is not foreclosed by actions taken in the planning period. The process of developing these alternatives would probably occur concurrently, with feedbacks between the two types of alternatives clarifying both the proposed actions in the plan period, and the alternatives which would remain for the future.

Area Analysis

While the objectives are being identified, a related task will be to provide a structure for the analysis of the alternatives. Once again, the analysis must be comprehensive, even if the resources available to do the analysis lead to a superficial analysis in some areas. The scoping process as well as direction from Forest Planning Teams should assist in identifying the aspects of the analysis needing the most effort.

At this point, the detailed and site specific information gathered in the inventory can be evaluated. Computer models can be used to assist in this analysis and also to assist in the generation of alternatives. While use of a single integrated model may be an efficient way to accomplish this in some situations, it may not be appropriate in others. In some cases, there may not be a need for computer models at all. To develop information and alternative schedules for timber harvest, site specific timber and engineering models could be used. For information on recreation opportunities, other models or an non-modeled analysis can be used. For wildlife, there can be some use of timber scheduling models or use of wildlife habitat capability and dispersion models. Whether single or multiple models are used with pre or post-processors does not matter. What is important is that each model uses the same information about the area and its alternatives.

Since the purpose of computer analysis is to analyze the consequences of an alternative, there is no need to force the construction of a perfectly efficient alternative, only feasible alternatives (for "action alternatives") or possible alternatives (for "planning alternatives"). Indeed, the entire economic analysis could be done outside of computer models by attaching a schedule of costs and benefits to each alternative. This kind of economic analysis can consider efficiencies such as reduced administrative costs and economies of scale which cannot be considered in "per acre" type models. It can also focus in on individual sale packages to identify "below-cost sales."

Products of the Area Analysis

The key short term product of the analysis is the selection of the "action alternative." To date, reaching this "action" decision has been the focus of most Area Planning. This decision would include a more detailed identification of site specific management objectives consistent with the Forest Plan. A site specific schedule of proposed management activities such as timber sales, road construction, recreation investments, silvicultural activities, range management, etc., would also be part of "action" decision. A related component would be an identification of the environmental consequences and options remaining for the future which result from the "Action" decision. These would derive from "planning alternatives" consistent with the "Action" decision. This information can be used in NEPA documents to support the actions identified for implementation in the plan period.

The bridge to Forest Planning can be served by retaining the information on the "planning alternatives" which are not foreclosed by the "action" decision. These alternatives can be stored in a computer and narrative format to serve as building blocks for the development of the next Forest Plan. In addition, the analysis and the "planning alternatives" provide a wealth of information about the area itself. This information would include not only the improved data in GIS, but also written information about the area's character and options for future management. This could be valuable to future managers of the area.

Relationship to Forest Planning

Under ideal circumstances, each area of the Forest would have some kind of an Area analysis done to provide "planning alternatives" for the future. Since these alternatives were developed by the Field, there are presumably implementable and would reflect the best information available at the time. In the next Forest Planning process, Forestwide objectives would be

developed for a new set of alternatives. To meet these objectives one "planning alternative" would be selected for each identified Area of the Forest.

Obviously, achievement of this ideal would require a reasonably consistent level of information from each Area (thus the need for comprehensive inventories and analysis, even if superficial), an adequate range of "planning alternatives" from each Area (to provide a wide range of Forest alternatives and meet such objectives as nondeclining flow), careful coordination of Area Planning processes at both the District and Forest level, and a Forest commitment supported Regionally and Nationally to produce a number of these Area Plans in a time frame that permits their use in Forest Planning. The Forest Planning team role has to be one of active managers and a source of technical support to Districts in this Area Planning process.

The more Forest Planning teams develop manuals or "cookbooks" on how to do Area Planning and provide some team leadership and technical support, the easier it will be to focus on the substantive parts of the planning process. Where resources or concern for a particular part of the analysis is limited, data from the Forest Plan may be used in Area Planning. These efforts can prevent each Area planning effort from having to "reinvent the wheel" while ensuring that Area Planning is done in a coordinated and efficient manner.

It may not be possible to get a complete set of "planning alternatives" for each Area identified on the Forest. Some aspects of "planning alternatives" will need to be reviewed to insure that they meet certain "state-of-the-art" technical standards for Forest Planning. In either case, Forest Planning Teams may need to spend some time either developing or refining the alternatives for certain specific areas.

Where commitment to Area Based Forest Planning is lacking, there still remains a capability to use the information from completed area analyses, as long as they were developed with an objective of providing meaningful input to the Forest Plan. This has already happened to some extent in many Forests, where management of certain areas has been determined by planning processes at the District level. However, an organization that continues to prepare its incremental actions with varying planning area boundaries in a non-comprehensive manner will find it difficult to use information developed from incremental analyses in future Forest Planning. In this case, the next round of comprehensive Forest Planning will proceed separately from the incremental planning work which has already been done.

Despite some of the difficulties in achieving the ideal relationship between Area and Forest Planning, a significant effort is likely to yield considerable benefits. These would include a better understanding of planning at all levels of the organization. Greater ownership in the Planning process will result in increased internal and external credibility for both Forest Plans and Area Plans. The wider participation in the planning process will provide opportunities for new ideas in Forest planning and implementation. It will also allow the public an opportunity to understand and participate in Planning on an area specific level as well as the Forest level.

Modeling Area Based Forest Planning

In the past decade most National Forests have gone from a status of having limited computer access to only large mainframe computer systems to a nearly complete reliance on an interconnected computer network. The future promises increased use of microcomputers and better use of GIS systems. As the reliance on computers within the organization has increased, so has the need to develop computer systems which communicate with each other and can exchange information between computers and levels of the organization.

Area Based Forest Planning would need to meet these same realities if it is to succeed as the principal method of planning Forest Service activities and land management. As indicated before there need not be a requirement that all area analyses use the same computer models. However, each area analysis would need to be able to produce similar products and provide for computer storage of information in a consistent format, even if the analyses were developed with different models. Within this framework, each functional area in Forest management should be able to use the appropriate computer tools needed to analyze the effects of each alternative under consideration. Where computers are used to assist in the generation or identification of alternatives, interdisciplinary involvement would be necessary.

Forests may prefer to establish procedures for the use of consistent models for certain types of area problems. The benefits of using consistent models would be increased technical support at the Forest, Regional, or National level; greater ease in assimilating area analyses into Forest analyses; and greater efficiency in completing area analysis. These advantages would have to be weighed against the prospect of committing to a model which may prove too restrictive, inefficient, or inappropriate for a wide range of area analyses.

One approach previously suggested (Connelly 1986) would be to use a family of interrelated FORPLAN models in this manner. Area analyses could use network equipped FORPLAN in an interdisciplinary environment to develop a set of planning and action alternatives for each area. The Area FORPLAN models would be used primarily for identifying timber schedules and accompanying road construction to meet various objectives. Other resources such as wildlife, recreation, and range would be involved in the design of objectives for the FORPLAN model, and could use either FORPLAN or other models to analyze the effects of the alternatives. The FORPLAN developed information along with additional information on each alternative developed outside of FORPLAN could be collapsed into a single column in a Forestwide model. Conversely, Forestwide models could be stripped down to assist area analysis. Models could be linked in a single system.

At the Forest level, each of the "planning alternatives" developed for each Area would be represented as a single column in a Forest matrix linear programming problem. Thus each Area develops a set of alternatives as follows:

AREA 1 AREA 2 ...AREA n

$$\{PA_{1,1}, PA_{1,2}..PA_{1,m1}\}\ \{PA_{2,1}..PA_{2,m2}\}\ ...\{PA_{n,1}..PA_{n,mn}\}$$

where each $PA_{n,mn}$ represents a "planning alternative" variable with all of its associated activities and outputs. This includes narrative or other information not involved in the linear programming model. There are $_n$ areas represented each with its own $_{mn}$ number of alternatives. Permissible values for each PA variable would range between 0 and 1. Representing this structure into a sample matrix would produce the following types of equations:

Area Control for Area 1

$$1PA_{1,1} + 1PA_{1,2} + ..1PA_{1,m1} + 0PA_{2,1}, \quad +$$
$$..0PA2_{,m2} + ..0PA_{n,1} + ..0PA_{n,mn} \quad = \quad 1$$

Timber Volume per decade (coefficients represent MMCF per decade)

$$4.3PA_{1,1} + 3.3PA_{1,2} + ..0PA_{1,m1} + 10PA_{2,1} \quad +$$
$$..1PA_{2,m2} + ...3.2PA_{n,1} + ..0PA_{n,mn} \quad <>=MMCF_1$$
$$4.3PA_{1,1} + 3.0PA_{1,2} + ..1PA_{1,m1} + 5PA_{2,1} \quad +$$
$$..2PA_{2,m2} + ...3.2PA_{n,1} + ..0PA_{n,mn} \quad <>=MMCF_2$$

Thus alternative $PA_{1,1}$ represents a nondeclining flow schedule, alternative $PA_{1,2}$ represents a small departure, and $PA_{1,m1}$ represents a deferred harvest schedule for Area 1.

Old Growth per decade (coefficients represent Thousand Acres of old growth)

$$2.5PA_{1,1} + 4.0PA_{1,2} + ..8PA_{1,m1} + 4PA_{2,1} \quad +$$
$$..16PA_{2,m2} + ...10PA_{n,1} + ..12PA_{n,mn} \quad <>=MAcres_1$$
$$2.0PA_{1,1} + 3.3PA_{1,2} + ..7.8PA_{1,m1} + 1PA_{2,1} \quad +$$
$$.15PA_{2,m2} + ...9PA_{n,1} + ..12PA_{n,mn} \quad <>=MAcres_2$$

Thus Area 2 is shown to be a larger area in terms of old growth than Area 1, and the two alternatives shown for Area 2 are far more different from each other than the alternatives presented for Area 1.

PNV over the Planning Horizon (Millions of Dollars)

$$.65PA_{1,1} + .80PA_{1,2} + ..\ .15PA_{1,m1} + 1.1PA_{2,1} \quad +$$
$$..\ .5PA_{2,m2} + ...\ .5PA_{n,1} + ..\ .2PA_{n,mn} \quad =PNV$$

Alternative $PA_{1,1}$ is shown to be a less efficient alternative than $PA_{1,2}$, despite its harvest of more volume in the first decade.

Additional special rows and columns may be added to the matrix for cumulative

Forest and temporal relationships such as nondeclining flow or departure bounds, multi-area traffic control, or the flow of forage for big game or livestock over time. Obviously, in seeking either 0 or 1 solutions for each variable representing a "planning alternative," a linear programming solution may produce fractions between 0 and 1. A variety of mechanisms may be used to resolve this problem, including beginning with a review of the solution to determine why the fractional values occurred. Since the solution being sought to the Forestwide problem involves a combination of one alternative for each area, these combinations may be tested against all of the various Forestwide objectives until an appropriate, but not necessarily optimal, combination is identified. An algorithm added to the linear program package could facilitate this testing.

It is likely that the principal objection to this approach to Forest modeling would be that an inadequate range of timber harvest schedules and intensities is being considered, thus leading to a loss of overall Forest timber production. This objection ignores the fact that optimization on a very large set of harvest schedules with per acre models may produce more timber volume in model solutions than can actually be implemented on the ground. However, collapsing timber schedules on an area basis will require that a considerable range of implementable harvest schedules be developed for each area. Unlike per acre models, these schedules would have been assessed by the Field and identified as potentially implementable. Another consideration is that the addition of site specificity may enable better representation of Timber yields for a Forest, possibly resulting in even higher timber levels than yields developed over broadly averaged Forest strata.

Conclusion

This paper has emphasized the advantages of using area planning for three principal purposes: (1) as a basis for developing individual projects to implement an existing Forest Plan, (2) to provide a record of detailed area information including identified future management options, and (3) to provide area specific alternatives for future Forest Plans. This does not mean that there might not be some disadvantages. Planning and data management activities would need explicit recognition as an independent and vital part of the National Forest management. People and dollars would be needed to support such a concept. Careful control of the entire planning process would become a priority mission for the Forest Service.

From my point of view, moving to Area Planning is inevitable in the long run. When I contemplate the value of such a planning process versus any increased costs, I'm sure that this would represent more efficient Forest management. The magnitude of any increased costs can also be controlled through better coordination and reduced duplication of Planning effort. More efficient use of GIS and other computer capabilities promises to make initial data gathering much simpler than it has been in the past. The Forest Service is already headed in this direction; the question is whether or not it will seize the initiative for this future.

Prior to the passage of NEPA and NFMA, the National Forests were incrementally managed to meet identified targets and programs. Planning could focus on just management of a single program or a single incremental decision. Multiple use management, although understood as part of the agency's mission, did not require as much in terms of planning since the Forests had a capability to meet nearly all of society's demands for Forest resources.

The passage of RPA-NFMA heralded the end of that period and the beginning of a new period of comprehensive Forest planning to meet multiple use objectives. These acts recognized that demand for Forest resources were beginning to exceed supplies. Comprehensive management plans would be needed to balance the conflicting uses of the land. The initial round of Forest Planning has sought to meet these multiple uses primarily through a zoning model of land allocation to emphasize a particular use. There are some who feel that it is inevitable that National Forest management will break down into separate areas managed primarily for single use purposes. Area planning and Area Based Forest Planning would require consideration and some integration of multiple use planning objectives in the management of each area. As such it represents the best opportunity the Forest Service has to demonstrate that multiple use management on all Forest lands can better serve our nation's needs than segregated single use management.

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Using Priced and Unpriced Values to Make Environmental Decisions

Elwood L. Schaffer and James B. Davis[1]

Abstract.--A process is described for making comparative valuations of a wide range of environmental management activities when the combined social, economic, managerial, and political benefits of some (but not all) of these activities cannot be adequately described in economic terms, and budgetary constraints do not permit funding all activities under consideration. The process accounts for subjective judgment and contains a formal rigorous decision strategy that takes the place of intuition when quantitative and qualitative values of environmental activities need to be evaluated.

The qualities that make a good manager come down to decisiveness. "You can use the fanciest computers in the world and you can gather all the charts and numbers, but in the end you have to bring all your information together, set up a time table, and act" (Iacocca 1984). The decision process described in this paper is intended to assist managers of natural environments in taking that action.

In many ways the quality and quantity of natural environments in the year 2000 and beyond are being determined and shaped by today's long-range planning activities and priorities. Yet, the expected benefits that may emerge from some of these activities can only be speculative at best. To be effective, long-range planning and priority-setting efforts must account for subjective judgment and contain formal, rigorous decision strategies that replace intuition (McCormack 1984, Peters and Austin 1985).

This paper describes a method to set priorities among a wide range of environmental management activities by using subjectively derived benefit scores and projected costs. The method was used initially in a variety of priority exercises in USDA Forest Service research but has also been applied by executives, negotiators, policymakers, analysts, and others who need to make decisions under uncertainty and risk when the dollar value of the benefits are unknown (Davis 1987; Davis and Schaffer 1984; Schaffer et al. 1977; National Agricultural Advisory Research and Extension Users Advisory Board 1983, 1984; USDA Forest Service 1983). The basic premise in the process is that human judgment is indispensable to decisionmaking in long-range planning (Harris 1964, Shelly and Ryan 1964).

[1]*Professor, Pennsylvania State University, University Park, PA 16802, USA; and Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, CA 92507, USA.*

The Problem Of Setting Priorities

In any organization, budgetary constraints do not permit funding all the actions or initiatives the organization wishes to pursue. Inevitably, managers are forced to set priorities on what they do, and frequently priorities must be set on some projects or efforts that cannot be evaluated through conventional economic benefit-cost analysis.

For example, suppose a forest manager has to choose between concentrating limited financial resources on (1) an effort to increase saw timber volume production or (2) increase opportunities for nonmotorized, dispersed recreation opportunities in remote scenic areas. Economists can make a benefit-cost analysis of the benefits to be derived from the timber production, but the social benefits associated with an effort to enhance access to scenic quality are not easy, and sometimes impossible, to describe in economic terms. The problem is how to decide, given limited budgets, whether to invest in timber production or access to scenic quality.

The decision theory literature is filled with examples, some much more complex than the one just described, of how executives, when faced with a difficult, complex decision, traditionally gather information or appoint a committee to do it, or both (Austin 1966, Kahn et al. 1964, Richards and Greenlaw 1972). As a result, an executive may be overwhelmed with

difficult to evaluate data, or become mired in trade-off considerations as proponents push favorite programs. When decisions are made, it may be difficult to discover why the choice was made. There is no "audit trail."

A Design For Making Decisive Decisions

The design described below does not make decisions and it does not portend what to decide. Rather, it helps facilitate consensus and defines priorities by using coherent decisions consistent with stated values of the decisionmakers themselves.

The design involves seven steps:

1. List items to be evaluated.
2. Select a panel of objective evaluators.
3. Survey the panel to evaluate the items in terms of their overall benefits.
4. Compute benefit scores.
5. Estimate the costs.
6. Compare initial benefit scores and costs.
7. Adjust benefit scores to reflect management's values and beliefs.

Each step is now described using a hypothetical example of a forest manager who must make tradeoffs between environmental quality and the production of goods and services from the forest land under his direction. The same methods could be applied also to such diverse problems as selecting the "best" location of a new electric transmission line or deciding which of several alternative methods that should be used in solid waste disposal.

List the Items

Suppose a forest manager needs to arrange the following 10 management activities, A through J, in order of priority, based on the overall benefits and estimated costs for each.

A. Increase saw timber volume production.

B. Initiate water yield improvement measures.

C. Increase scenic highway development.

D. Increase nonmotorized, dispersed recreation opportunities.

E. Develop a project for range grazing use improvement.

F. Increase the opportunities for developed recreation.

G. Improve wildlife habitat areas.

H. Improve fish habitat including spawning areas.

I. Reclaim areas adversely impacted in past mining operations.

J. Increase and improve winter sports and ski area development.

The manager estimates the total cost of all of the projects to be 250,000 dollars but only has a current operating budget of 150,000 dollars. The manager decides that each activity is independent of any other and that it will be more effective to complete as many projects as possible, rather than use a "piecemeal" approach in which several will be partly completed.

The words used to describe the 10 efforts (A through J) are typical statements involved in priority setting. For example, members of the National Agricultural Research and Extension Users Advisory Board (1984) used these kinds of broad, general descriptions of research (or management) efforts within the decision design described here--when recommending program priorities to Congress. At other management levels, the activities may need to be described more specifically. The question of "how specific" is a difficult one for two reasons. First, the number of alternative investment strategies available to the decisionmaker, even in the hypothetical example used here, may be extensive. Heterogeneous information bears on each investment strategy. Second, the decisionmaker is faced with imperfect knowledge about the expected costs of each activity, as well as considerable uncertainty about their benefits that may be difficult (in many cases impossible) to specify in a totally objective way. Many times total benefits of a given activity cannot be described very well even by the manager(s) most intimately involved with the program prioritization or selection (USDA Forest Service 1981). Nonetheless, the programs and their expected results should be described in the context of the combined political, social, economic, managerial, and environmental values of each one. The degree of generality or specificity of the description of each management activity is kept as uniform or as parallel as possible. This is not easy--especially if there are a large number of activities to be evaluated and prioritized.

In addition, the expected results from management activities within each of the 10 activities must be described. For example, some of the potential results under project F--Increase nonmotorized, dispersed recreation opportunities might be:

> Physical experience--the opportunity for physical exercise and exertion that stimulates the body.
>
> Emotional experience--the thrill of experiencing new sensations and exploring wild regions--experiences that deal with an achievement of some sort.
>
> Aesthetic experiences--the enjoyment of the beauties and variety of relationships that exist in natural environments.
>
> Educational experiences--the opportunity to gain new knowledge or teach others about the soil, water, wildlife, plant, and other scenic resources.
>
> Social experiences--the chance to engage in conversations ranging from brief casual meetings to more lengthy conversations with companions or during stops at overnight camps (Schaffer and Mietz 1969).

Select a Panel

The second step is to select a panel of knowledgeable people to make judgments about the importance of the items to be evaluated. The number to include on the panel depends on the variation in the subjects to be considered. It is not always easy to separate scientific competence from policy involvement; indeed, that may be partly due to involvement in policy. On the other hand, selecting panelists purely for managerial or scientific competence may give results that are tilted toward one side of a policy debate. Select panelists who are "honest brokers," people who are willing to be objective in judging overall program benefits of the items being evaluated.

Conduct a Survey

Third, panelists are given or mailed a description of the activities (10 in our example), background information such as a list of the results from each activity, and a survey form (table 1). Everyone compares the 10 activities, two at a time, on the bases of overall perceived environmental, social, economic, managerial, and political benefits. Timeliness is an important consideration. Programs whose benefits may only be derived in the distant future usually should not be considered as valuable as a program that will show immediate benefits.

An important limitation on the paired comparison method is the practical limit on how many items can be compared. The equation is:

$$f = \frac{n(n-1)}{2}$$

where "f" is the number of paired comparisons and "n" is the number of things compared. In the hypothetical example, "n" equaled 10; consequently there were 45 comparisons--about as many as one can expect from a panel of busy people.

There are at least three major reasons why a mailed survey is recommended over group discussions. One is cost. Second, fuzzy thinking abounds in initial group discussions of this kind. The desire for solidity among panelists can cloud the initial analysis and thinking necessary to reach a balanced decision (Janis 1983). The third is "band wagon jumping." There is a strong desire for many to agree with others even though they believe or possess information that might lead to a different conclusion.

Methods for estimating the overall value of a large number of diverse items under these circumstances have been developed in a wide range of disciplines--including economics, political science, psychology, and sociology. Despite differences in approach, these methods tend to blend. Pair-wise comparing all items, two at a time, may be used; for example, to derive an attitude scale for a psychologist (Bock and Jones 1968, Edwards 1957, Torgerson 1958) or a utility scale for an economist (Sinden and Worrell 1979). In fact, the various disciplines often use different terms for the same thing. Economists make the most use of these methods as value indicators for making priority decisions.

Compute Benefit Score

Fourth, the benefit scores are computed. The percentage of times all respondents select each activity over every other provides the basic data for computing (Edwards 1957, Ross 1934) the benefit scores (table 2). Note that the benefit scores are normalized (values systematically changed), so that they sum to 1000. The units of "benefit" are not specified--they can be considered as units of utility if one wishes.

Table 1.--Survey forms and hypothetical entries of how one panelist compared all two-way sets of 10 projects.

	A	B	C	D	E	F	G	H	I	J
Items	Sawtimber production	Water yield	Scenic highway	Dispersed recreation	Range improvement	Developed recreation	Wildlife habitat	Fish habitat	Mining & oil	Ski development
A. Sawtimber production	X	1	1	1	0	1	1	0	1	0
B. Water yield		X	1	1	0	1	1	0	0	0
C. Scenic highway			X	1	0	0	1	0	0	0
D. Dispersed recreation				X	0	0	0	0	0	0
E. Range improvement					X	1	1	1	1	1
F. Developed recreation						X	1	0	0	0
G. Wildlife habitat							X	0	0	0
H. Fish habitat								X	1	0
I. Mining & oil									X	0
J. Ski development										X

A "1" indicates the benefits of the column item judged more favorable than the benefits of the row item. A "0" means just the opposite.

Table 2.--Hypothetical example of how benefit scores were calculated for 10 land management activities.1,2,3.

Items	A Sawtimber production	B Water yield	C Scenic highway	D Dispersed recreation	E Range improvement	F Developed recreation	G Wildlife habitat	H Fish habitat	I Mining & oil	J Ski development
	--Proportion of times column research effort was judged more favorable than row research effort--									
A. Sawtimber production	.00	.70[1]	.15	.10	.15	.15	.60	.00	.60	.10
B. Water yield	.30[2]	.00	.00	.00	.15	.30	.45	.25	.45	.25
C. Scenic highway	.85	1.00	.00	.30	.60	.70	.60	.25	.60	.30
D. Dispersed recreation	.90	1.00	.70	.00	.85	.70	.75	.55	.75	.85
E. Range improvement	.85	.85	.40	.15	.00	.55	.60	.40	.75	.60
F. Developed recreation	.85	.70	.30	.30	.45	.00	.75	.30	.60	.55
G. Wildlife habitat	.40	.55	.40	.25	.40	.25	.00	.25	.55	.25
H. Fish habitat	1.00	.75	.75	.45	.60	.70	.75	.00	.75	.70
I. Mining & oil	.40	.55	.40	.25	.25	.40	.45	.25	.00	.25
J. Ski development	.90	.75	.70	.15	.40	.45	.75	.30	.75	.00
Totals (Grand Total = 45.00)	6.45	6.85	3.80	1.95	3.85	4.20	5.70	2.55	5.80	3.85
Benefit scores (Total benefit scores = 1000)	143[3]	152	84	43	86	93	127	57	129	86

[1]Let's assume 10 panelists were used in this survey. We add the individual raw scores from the survey forms (for example 1+1+0+1+1+0+1+1+1 = 7) and divide the number of panelists (7/10 = 0.70).

[2]The value in a cell to the left of the diagonal dashed line is: 1.00 minus the corresponding pair-wise comparison value to the right of the diagonal. For example, the 0.30 in the first column, row two, is the result of 1.00-0.70; the 0.70 is being located in the second column, row one.

[3]Benefit scores are normalized so that they sum to 1000; for example, 6.45/45.0 x 1000 = 143. Multiplying by 1000 is a convenience to avoid the use of decimal points in the benefit scores.

Estimate the Costs

Fifth, the annual cost of each activity needs to be estimated. This step should be done concurrently with, and independent of, the panel survey to develop benefit scores. Experienced persons should estimate the costs of each activity being evaluated without being influenced by the values of the benefit scores.

The total cost for each activity is discounted to present worth--the money needed today in order to fund the activity in total. The rate of interest is selected by the manager and based on prevailing discount rates. Only activities with similar timeframes should be compared. A project that will be quickly terminated, or one for which funding will be delayed, usually should not be compared with the others. Since costs are explicitly discounted, it is important that there be an implicit discounting of the benefits also, based on their expected delivery time.

Compared Initial Benefit Scores and Costs

A computer can quickly summarize results of the individual benefit scores provided by each panel member, as well as the costs for the 10 activities (table 3).

Each activity is then ranked and plotted according to benefit scores to form a benefit-only criterion curve. That is, the program with the highest benefit score (in this case B--initiate water yield improvement measures) is plotted first, against its cost. The program with the next highest benefit score (A--saw timber volume production) is plotted second, in a cumulative manner, until all projects are arranged along a curve (fig. 1).

Efforts are also plotted by a cost-benefit criterion. In this case, D (nonmotorized, dispersed recreation opportunities) is plotted first because it has the largest benefit-cost value (table 3), H (fish habitat improvement) is next, etc. (fig. 1).

Table 3.--Initial and final results after fine tuning the benefit scores of the 10 activities.

Research effort	Initial results			Final results	
	Initial benefit score	Discounted cost (millions)	Initial benefit/cost criterion value	Final benefit score	Final benefit/ cost criterion value
B. Water yield	152	16	9.50	216	13.50
A. Sawtimber production	143	36	3.97	123	3.41
I. Mining & oil	129	56	2.30	164	2.93
G. Wildlife habitat	127	9	14.11	110	12.22
F. Developed recreation	93	30	3.10	80	2.67
E. Range improvement	86	20	4.30	74	3.70
J. Ski development	86	35	2.46	74	2.11
C. Scenic highway	84	26	3.23	72	2.77
H. Fish habitat	57	2	28.50	49	24.50
D. Dispersed recreation	43	1	43.00	38	38.00
Totals	1000	231		1000	

The two resulting curves provide a tool that can be used, along with other considerations, for making decisions about the priorities of the activities under various cost constraints. As figure 1 shows, the cost-benefit criterion curve always provides more benefit for a fixed investment. For example, if a program budget is set at 150,000 dollars, a program that contains efforts D, H, G, B, E, A, F, and C--with a total benefit score 800--is preferred, rather than a program with efforts B, A, I, G, and E--with a total benefit score of only 660 (fig. 1).

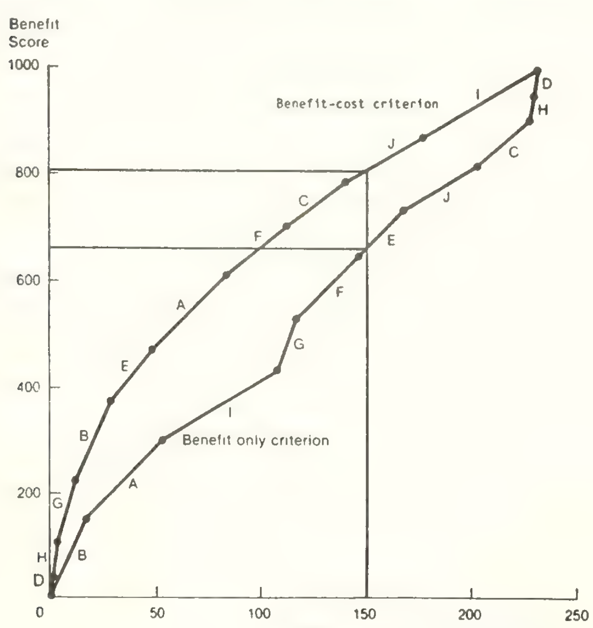

Figure 1.--Cost-benefit versus benefit-only criteria: initial results.

Adjustment by Management

The primary advantage of the decision-analytic approach, up to this point, is that it provides an organizing and clarifying framework for facilitating consensus in complex decisionmaking situations. However, since management is responsible for the final content and success of activities being considered, final decisions on content and benefits of the activities is theirs. Thus, management may wish to adjust the initial benefit scores based on social, political, economic, scientific, or environmental information not evident or important to panel members.

Such adjustment is a systematic method whereby management examines and may change benefit scores (and thus the location) of the activities along the cost-benefit criterion curve (Armstrong 1987). The only constraint is that regardless of the number of changes that are made, the sum of the scores must equal 1000. For example, if management wants to increase the benefit score of one activity, it needs to reduce the value of another, or others, an appropriate amount.

The adjustment process might work like this. Management compares the program package D, H, and G on the cost-benefit criterion curve with B on the benefit-only criterion curve. Both packages cost about the same, but the first has 1 1/2 times the benefit score value as the second. However, management may feel that B is more important than D, H, and G--regardless of what the data suggests (table 3). So, B's benefit score is adjusted--let's say 250. The reason(s) for the change is documented, and the scores of all of the other efforts along the curve are adjusted (that is normalized) so that their sum equals 1000.

Next, management observes that the package D, H, G, B, E, A, and F on the cost-benefit criterion curve have a higher total benefit for the same cost than the package with B, A, and I on the benefit-only criterion curve. Since B and A are common to both packages, and there is no interdependences among the efforts, I can be compared to D, H, G, E, and F. Let's assume management wants I's score changed to 190. The change is made, the data is renormalized, and the adjustment process continues until management is satisfied with the final benefit scores of all activities. Final benefit-cost data are computed (table 3), and a final set of curves are portrayed (fig. 2).

Figure 2 shows the optional order of investment for a dissimilar mix of activities. Note that for any arbitrary limit on cost, the best mix is defined (e.g., if the budget is $150,000, the best investment strategy is D, H, B, G, E, A, and I.

Limitations on the Design

1. The design for decision approximates the value of the items being considered--as perceived by panel members.

2. Results depend on the approximation used to define and specify the design.
3. Those approximations deal with the state-of-knowledge regarding interdependences, costs, benefits, uncertainties, risks, and timeliness of the effort.
4. Approximations are innate to complex problems and should be refined as better information becomes available.
5. Results reflect only the knowledge and judgment of the panel participants.
6. The system will be unfamiliar to most participants. However, when it is understood, it is usually accepted by managers and panelists and should have application to a wide range of environmental decisionmaking.

Advantages of the Design

1. Participants apply judgments to a set of well-designed, content-specific situations.
2. The procedure incorporates anticipated accomplishments; however, whenever this information is incomplete or unavailable, the panelists should use their judgment in keeping with their background and expertise.
3. The rational supporting subjective judgments is elicited and captured. Thus, the approach recognizes that human judgment is indispensable to the problem solution.

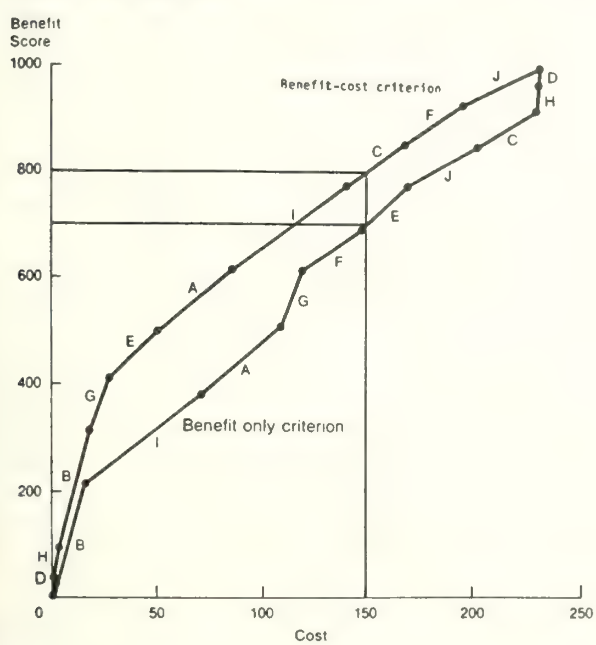

Figure 2.--Benefit-cost versus benefit-only criteria: final comparisons.

4. The system leaves an "audit trail" in which most decisions are made specific, many of them quantified.
5. The approach accommodates selective comparisons and tradeoff of dissimilar items. When comparing different items, panelists must evaluate relative consequences of various mixes of programs, no matter how diverse they might be.
6. Comparison through rational, informed, subjective judgment is an indispensable part of all decisions. The psychology of human choice requires it, and the design for decisions provides a logical foundation for capturing it.
7. The cost-benefit criterion curve is clearly linked to relative benefits with no issues hidden within the procedure.
8. The structure of decisions is visible and invites investigation, discovery, and constructive criticism. It facilitates challenge, sensitivity analysis, and improvement through debate.
9. Results can be used to gauge impacts of budget constraints and modifications.
10. This decisionmaking procedure under uncertainty can serve as the hub of an information system for overall program investment strategies. In turn, these strategies influence and promote decisive decisions that concern the social, economic, environmental, and practical realities of the environment.

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Stand Level Sensitivity Analysis on the Effect of Markets on Optimal Management Regimes

Joseph P. Roise, William Hafley, and William Smith[1]

Abstract.--This is a report on sensitivity of optimal loblolly pine stand management in relation to stumpage market price functions, stand quality, and merchandising criteria. Oriented strand board, high speed sawmills (scragg type mills), and a combination of the two are the three stumpage markets. When size and quality are important for a stumpage market manufacturing process, lower initial planting densities are required; but they must be high enough to maintain wood quality. Also thinning, if any, is precommercial and rotation age is longer. For markets where quality and size have little effect on price, oriented strand board, planting densities are high, rotations are short, and there are no thinnings. For a stumpage market which has both lumber and fiber manufacturing processes, optimal stand management is sensitive to relative manufacturing costs. Optimal management regimes are highly dependent on markets.

Speaking candidly, it is an impossible task to determine optimal stand management regimes. This is said in recognition of an unknown future. The mathematics are simple. It is the information requirements which are impossible. We can do a reasonable job of predicting growth and yield of timber stands. However, we do a relatively poor job of predicting the future for a wide variety of economic, physical, and biological factors including markets, manufacturing technology, interest rates, prices, production costs, risk, timber quality, and nontimber site factors among others.

Where does this leave us? With our knowledge of stand level management, we can make "intelligent" guesses on the state of future factors and we can study how variations in factors affect optimal decisions. This is where sensitivity analysis plays an important roll.

Every timber stand has a unique set of factors which affect optimal management regimes. These factors can be classified as either control variables, those which management can influence, or noncontrol variables over which management has no influence. Several stand management optimization studies have recognized noncontrollable variation in factors, and accordingly, contain a sensitivity analysis of control and noncontrol variables. Noncontrol variables over which sensitivity analysis has been performed include: management objective, stumpage price function, site quality, interest rate, regeneration cost, initial stocking, and risk.

This paper reports on a sensitivity analysis study of stand level management to market type: high speed sawmills, oriented strand board, and a mix of the two. Also included are the impacts of changing petroleum prices, merchandising criteria, and stem quality. Stem quality is defined in terms of differences in limbiness associated with stand density. The North Carolina State University Loblolly Pine Plantation Management Simulator (Hafley and Buford 1985) was used as the basis for the optimization. Nonlinear programming, as reported by Roise (1986), was used to locate optimal points. Thinning strategy was limited throughout to one commercial thinning.

Since tree quality has not been a factor in previous loblolly pine stand management sensitivity, an additional objective of this study was to demonstrate both a rationale for its inclusion in optimization studies and its impact on the location of the optimum. Since southern pine grading rules place a high premium on knot size, limbiness was chosen as a surrogate for grade. In a recent article, Briggs (1987) considered quality in a Douglas fir stand optimization study. Though preliminary in nature his article points out the importance of including quality in growth and yield predictions and optimization studies.

[1] *The authors are respectively Assistant Professor, Professor, and Instructor, College of Forest Resources, North Carolina State University, Box 8002, Raleigh, NC 27689.*

PRICE FUNCTION SENSITIVITY

Managers are interested in more than single point optima. Rather, they are interested in the whole range of management possibilities and how changes will affect bottom line results. For this reason, we have chosen to report our results as response function maps which encompass the optimal point. This is in recognition that even though optimal stand management is a desirable goal, forest management requires trade offs between activities which, in turn, lead to "suboptimal" combinations of activities. Thus, it is important to understand sensitivity to alternatives.

The control variables in this study are planting density, single thinning time and intensity, and harvest age. The noncontrol variable, over which management sensitivity is examined, is the price function. Three price functions are used. One for an oriented strand board plant (OSB), one for a high speed sawmill (HSS), and one for a merchandised combination of the two (MIX). Appendix A summarizes the three price functions and all assumptions.

As stated earlier, published literature indicates little agreement on the structure, use, and results from different stumpage price functions. This is because a unique price function can be derived for almost every situation. Land owners selling stumpage use market price. An integrated forest products firm may use an internal transfer price. A pulpwood market price may be based on quantity. A veneer-wood market price is based on both quantity and quality. Hotlvedt and Straka (1987) note that stands are commonly evaluated using expected regional average stumpage prices which are discontinuous from one product to another, cyclical and subject to wide geographic variation. Not surprisingly, these prices do not apply to any specific situation. They are appropriate only for regional decisions and could lead to incorrect results when applied to specific or local situations.

What implications do price functions have on stand management decision making? The use of the wrong price function can lead to erroneous decisions when comparing just two stand management regimes and large errors in estimating optimal management regimes. An alternative to average price for stumpage is residual value price. Residual value is gross revenue from sale of end products from a tree minus total cost of converting the tree into the final products. A logical wood product producer will value a tree, as part of a stand, based on internal firm residual values. In a competitive bidding environment, this will be reflected in stumpage price. The more suitable the raw material in a stand is for a bidders manufacturing process, the more that can be paid. Nonetheless, what is paid and what could be paid are two different amounts. Buyers want to maximize and sellers want to minimize the difference between these two amounts. For the buyer, the difference is profit. For the seller the difference is lost profit. Therefore, the use of the wrong price function would lead to an erroneous estimation of profit.

Table 1.-- Range of price functions analyzed. Numbers refer to unique cases. All 1's are the same case, all 2's are the same case, and so on. For the mixed market it is assumed that wood is allocated to the market of highest value. The following statements describe the difference between cases: changes in wax and resin price does not impact wood quality; changes in stand density does not change OSB value; harvesting cost is a function of diameter alone; the cost of competition suppression at low densities is not included; the increased knot and limb size at lower densities only affects wood value in cases 10 and 11.

Case descriptions Price and density factors	Type of market Oriented stand board	 High speed sawmill	 Mixed market
No density adjustments 1985 price of wax and resin	1	2	3 (1+2)
No density adjustments Double 1986 price of wax and resin	4	2	5 (4+2)
No density adjustment Triple 1985 price of wax and resin	6	2	7 (6+2)
Wood from live crown cannot be used as sawtimber 1985 price for wax and resin	1	8	9 (4+8)
Sawtimber value decreasing with planting density 1985 price for wax and resin	1	10	11 (4+10)

Price Functions for Three Markets

This section examines loblolly pine stand management in relation to stumpage price functions. The different price functions examined are listed in table 1. As used here, stumpage price is a function of market, tree quality, and diameter class. Three variations are made to the basic raw wood market types: one deals with an external cost factor, one with merchandising, and the last with quality. The external factor is the cost of wax and resin in the manufacture of OSB. Wax and resin, petrochemicals, are assumed to be linearly related to the cost of crude oil. Harpole (1985) in a comparison of isocyanate and phenol-formaldehyde bonding costs noted that cost per thousand square feet is highly sensitive to changes in wax and resin cost, more so than the cost of wood. The merchandising variation is to disallow wood within the live crown for use as sawtimber. To accomplish this, a function was developed to estimate crown ratio given the stand age and initial spacing (appendix B). Concern for quality is a reason for maintaining "full" stocking. As density decreases, tree size increases but quality decreases. For this reason, we examine effect on optimal management practices to changes in raw wood characteristics caused by stand

density conditions. To accomplish this, the price function was modified such that as the planting density decreased below 400 trees per acre the value of sawtimber decreases linearly, until at a planting density of 100 trees per acre the sawtimber value is zero. Appendix A contains a complete summary of assumptions made in this study.

Timber purchasing competitiveness for alternative forest products manufacturing facilities was analyzed by Deal (1986). This required development of detailed residual stumpage price functions. In addition to OSB and HSS, he estimated price functions for conventional sawmills and medium density fiberboard plants. His HSS wood value is a function of tree diameter and height, while his OSB wood value is constant per unit, except for the effect of harvesting cost (appendix A). These prices represent the maximum amount a mill could be willing to pay for stumpage and still break even. Because of short expected rotation ages, it is assumed that plantation rotations will not produce any trees that grade better than Southern Pine Grade C.[2] Classifying all trees as grade C was suggested by examination of plantation spacing studies. Lumber grade yield was determined for grade C trees using the lumber grade yield method of Schroeder et al. (1968).

As a result, within this study, there are 15 price function combinations: three markets with and without crown merchandising adjustments, three markets with and without quality adjustments, and three markets with three different levels of external price for wax and resin (table 1).

Stand Management Results for Three Markets

Table 1 presents a listing of the combinations of market, merchandising, and external price (Case 1 through Case 11) used in this study. Summarizing the effect of the different cases on loblolly pine plantation management we find that: markets with constant price functions (like OSB) are optimal at high planting densities, no thinning, and short rotations. Markets with diameter sensitive price functions, like HSS, result in low optimal planting densities, no thinning, and longer rotations. However, markets with diameter and quality sensitive price functions result in intermediate optimal planting densities with a precommercial thin and even higher harvest ages. Markets with a mixed (OSB + HSS) price function lead to a wider range of stand management choices. Each market price function leads to a distinct optimal stand management regime. The results reflect trade offs made between three basic raw material characteristics: total stand volume, tree size, and wood quality. Optimal stand management is an attempt to equate the marginal value of each characteristic.

[2] Trees with no clear faces on the 16-foot grading section, or with 1 or 2 clear faces on the 16-foot grading section with sweep in the lower 12 feet of the grading section of more than 3 inches which equals or exceeds one-fourth of the diameter at breast height.

Oriented Strand Board Timber Markets

Stands with a price function having no premium for larger trees, except for logging costs (Case 1), should be planted at high densities, between 800 and 900 trees per acre, have no thinnings, and a rotation age of around 16 years (fig. 1a). This can be referred to as a fiber production rotation. The expectation of increasing manufacturing costs (Case 4 and 6, caused by increases in wax and resin price) should not cause significant changes in management of fiber production rotations (figs. 1b and 3c). However, the value of these rotations decrease noticeably. The value of a fiber production rotation is more sensitive to rotation age then to planting density. Figure 2 presents simulated results from four different planting densities on the total net undiscounted harvest value and volume per cubic foot by diameter class. Since the OSB price function does not place a premium on larger size trees, the optimal regime is to produce more volume in less time. Tree size has only a minor effect related to harvesting costs.

High Speed Sawmill Timber Markets

Three variations in the price function are considered here. The first, an over simplified case but one which is commonly used in optimal stand management studies, deals with stands that have an expected price function increasing with tree size only (Case 2). In this, case no loss is incurred due to quality degrade or restrictions of merchandising wood in the live crown. Near optimal management requires low planting densities (100 trees per acre), no thinning or a precommercial thinning at age 10, and final harvest at around 30 years. In this case, tree size is the driving factor.

A slightly more realistic case is for a stand with a price function increasing with size but with merchandising restrictions (figs. 3a and 3b, Case 8). The merchandising restrictions used in Case 8 are that wood in the live crown or wood above an 8-inch top, which ever comes first, can not be used for sawtimber. The crown ratio equations used are summarized in appendix figure B1. This restriction increases planting density in optimal management regimes, over Case 2. In this case, near optimal management would require planting densities around 200 trees per acre, with a precommercial thin, and final harvest around 32 years. In this case, the effect of tree size is mitigated some by the merchandising restrictions. However, tree size is still the driving factor.

The last case for HSS, Case 10, adds a concern regarding loss of wood quality (increased limbiness) as stand density decreases. (See appendix A for quality loss function.) In this case (figs. 5a and 5b, Case 10), optimal planting densities should be around 400 trees per acre, with a precommercial thinning around age 10, and final harvest around age 40. This planting density is probably an artifact of the assumed value loss function. Four hundred trees per acre is as low as the model will go without loss of quality. No investigation was made of the relation between

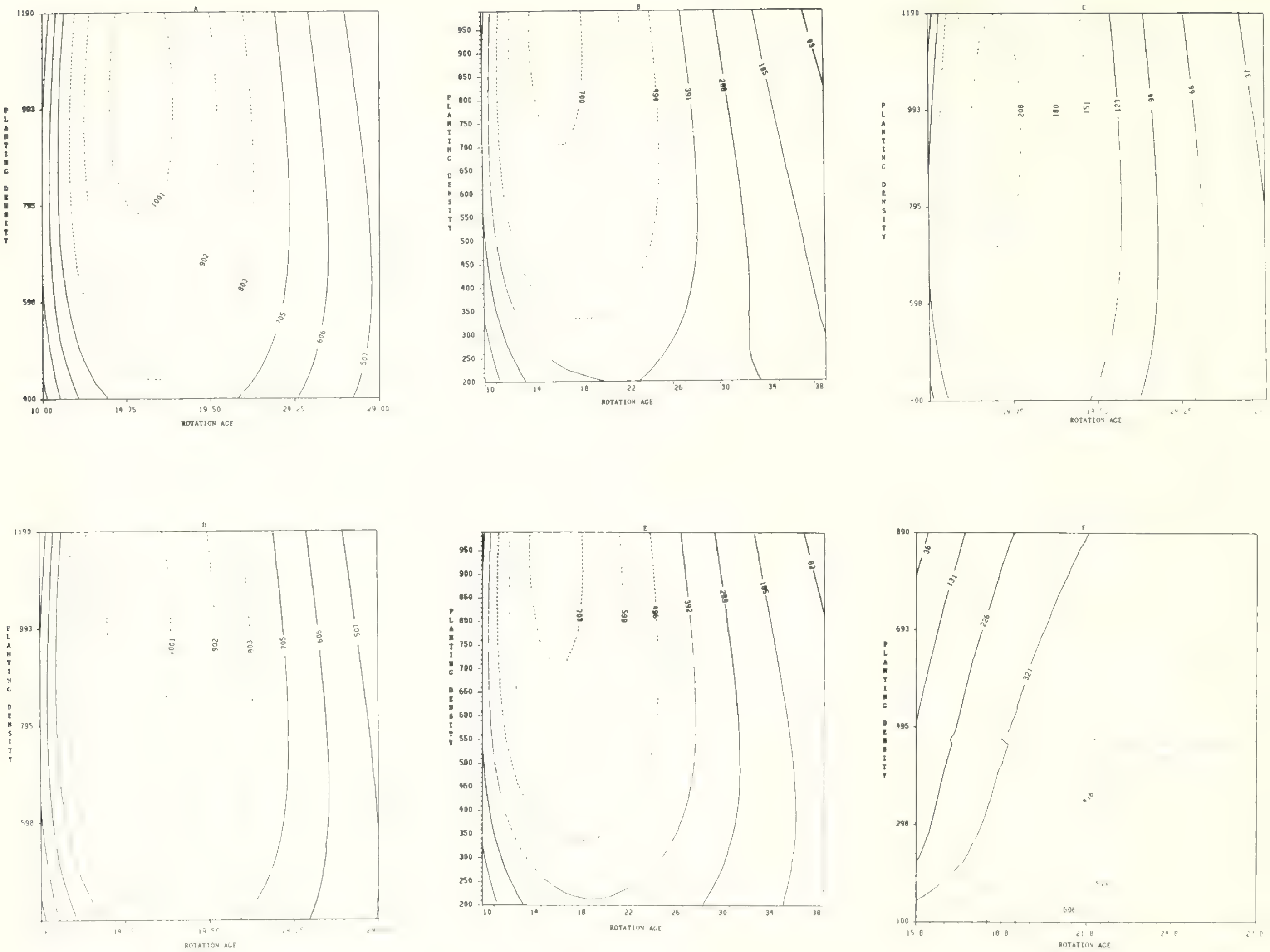

Figure 1.--Soil expectation value as a function of planting density and rotation age for oriented strand board (a, b, c) and mixed market price functions (d, e, f). In figures a and d, the price of wax and resin is at the 1984 market price. The two markets have almost identical results. OSB dominates the HSS price function. In figures b and e, the price of wax and resin is double the 1984 market price. Again, results are almost identical. OSB dominates the HSS price function. In figures c and f, the price of wax and resin is triple the 1984 market price. The differences are obvious. OSB results are the same as in the other cases. OSB is now clearly dominated by the HSS price function.

slope of the value loss function and planting density, or the starting point of the value loss function and planting density. The assumption of value loss is hypothetical and meant merely to illustrate concerns about planting low density. Figure 4 presents the effect of planting density on HSS yield by diameter class. Thinning is precommercial. This type of thin in the optimal solution is at least partially a result of the modeling assumptions. The value loss function is based only on initial planting density not on density after thin. So in order for the model to grow larger trees without value loss, the "best" option is to plant at densities high enough to avoid loss and thin back to lower densities as late as possible but before crowding. The major difference comes at final harvest where lower planting densities result in more larger trees but lower total volume and value. In this case, quality is driving the system as well as tree size and total volume.

A Mixture of OSB and HSS Markets

The final set of cases deal with simple two market combinations. In table 1, five different mixed market cases are listed: 3, 5, 7, 9, and 11. Case 3, figure 1d, has a price function which is a combination of case 1 and 2, OSB at current wax and resin prices, and HSS with price sensitive to diameter alone. This case results in exactly the same optimal regime as OSB alone (Case 1). Thus under these market conditions, a timber grower would

follow a fiber production regime and OSB would have a competitive advantage over saw timber. Case 5, figure 1e, indicates the impact of wax and resin price doubling. The fiber production rotation is still optimal. Note the change in shape of the response surface at lower densities in comparison to figure 1b. This is caused by a sawtimber local minimum, at lower densities and higher rotation age than included on the graph. Case 7, figure 1f, uses the same price function as Case 3, however, with the wax and resin price tripled. The optimum point on this graph is at 100 trees per acre and a rotation of 21 years. When the wax and resin price is tripled, a sawtimber rotation results. The cost of crude oil at the time of this analysis was $18.00 per barrel. If there is a linear relation between oil price and wax and resin price, then oil price can increase up to $36.00 per barrel and OSB regimes would still have a competitive advantage over sawtimber regimes; however, if oil price continues to increase, then somewhere between $36 and $54 per barrel sawtimber would have an advantage over OSB. Effectively, Case 7 has the same optimum as Case 2.

Case 9, figure 3c and 3d, has a price function which is a combination of OSB (Case 4) and HSS (Case 10). Two local optima were found. The largest local optimum has a planting density of 100 trees per acre, precommercial thin at age 10, and final harvest at 22 years. The second optimum has approximately 500 trees per acre, with a commercial thin at age 19 and final harvest at 38 years. Figure 5 presents two planting densities with the price function from Case 9. Note the dark shade is for the OSB market, the light shade is for the timber market. The major difference in the result is that there are more large stems at the lower density.

Case 11 (fig. 5c) has the most realistic price function. It is a combination of OSB (Case 4) and HSS (Case 10). Wood is allocated between OSB and HSS markets depending on where it is more highly valued, or if in the live crown or above an 8-inch top it is allocated to the OSB market. Wood allocated to the HSS market loses value when planting density is less than 400 trees per acre. Only a single optimal point was located. The difference between Case 9 (fig. 3c) and Case 11 (fig. 5c) is the

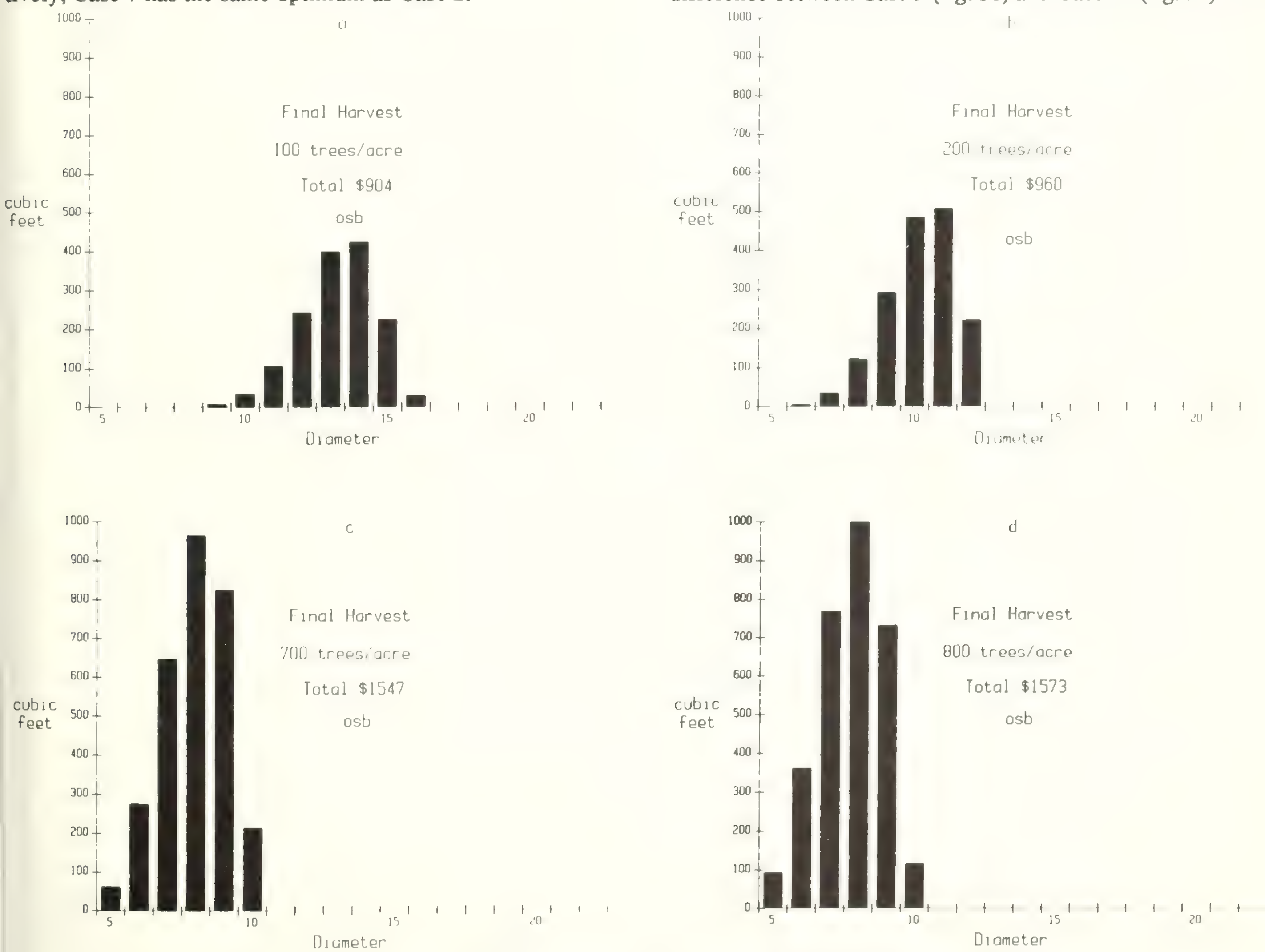

Figure 2.--Final harvest diameter distribution for four different initial planting densities. As planting density increases, average diameter decreases and net harvest value increases. The total net harvest value shown has not been discounted.

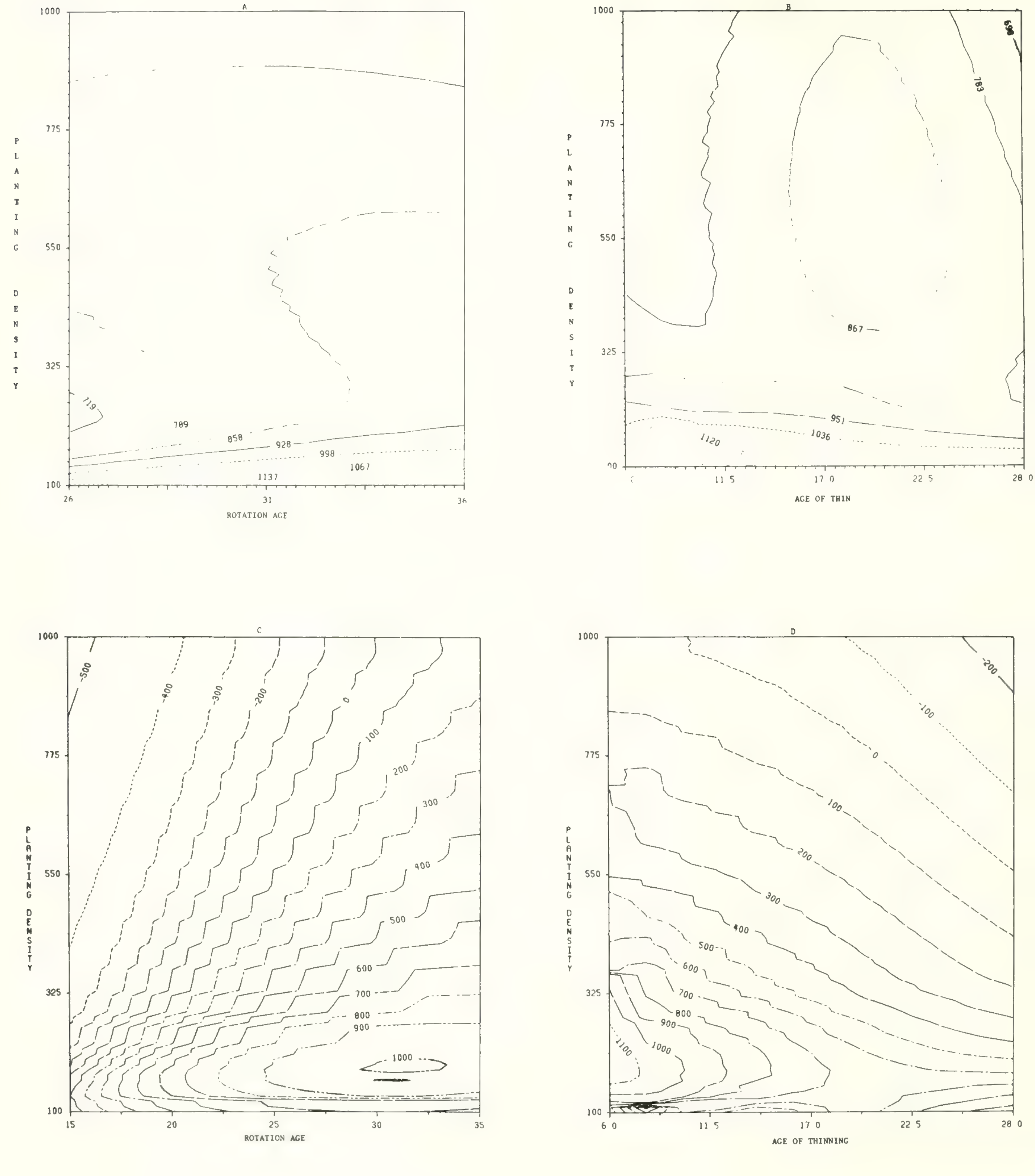

Figure 3.-- Soil expectation value as a function of planting density, rotation age (a and c), and thinning age (b and d) for high speed sawmills (a and b) and mixed markets (c and d).

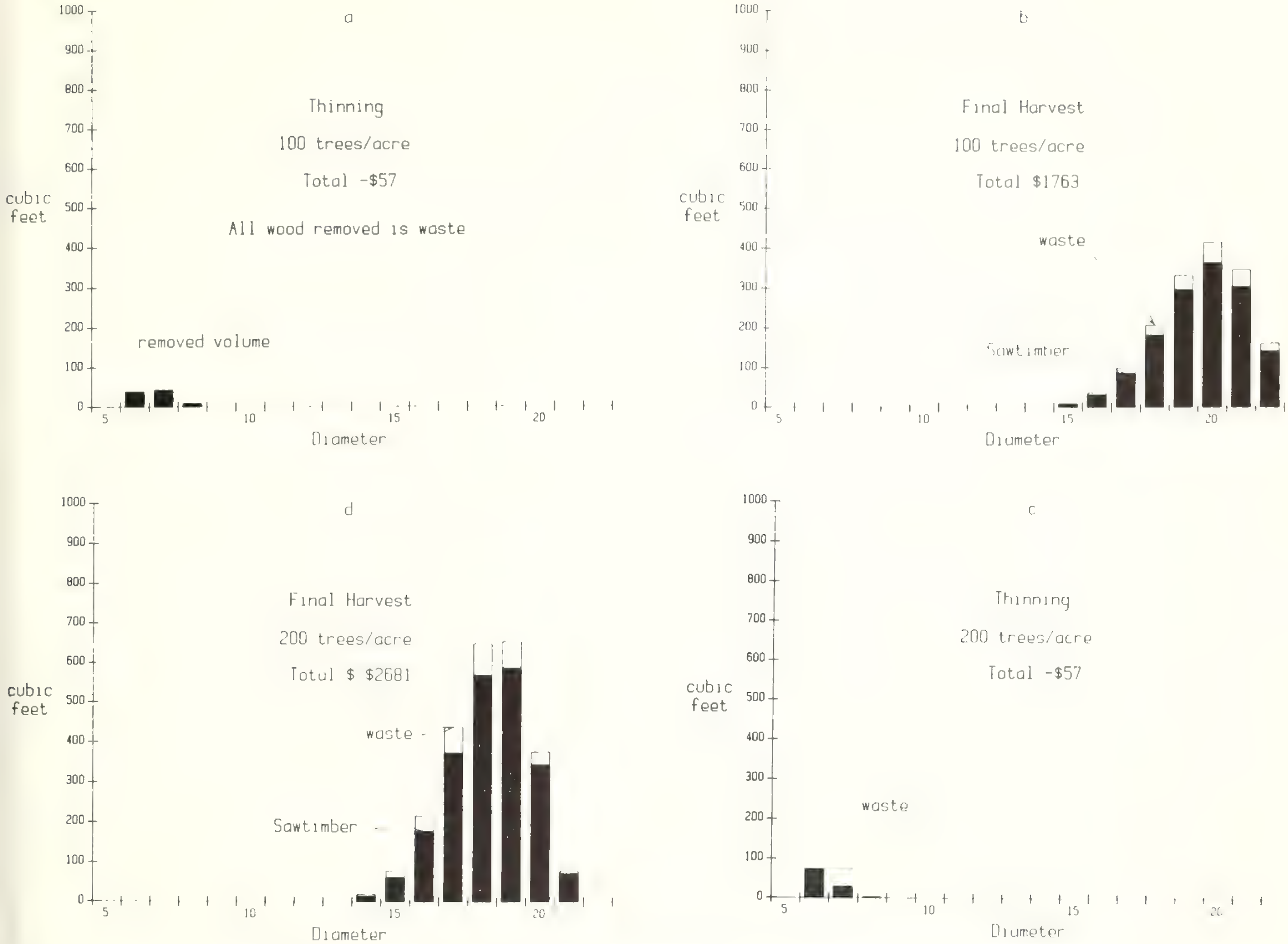

Figure 4.--Diameter distributions of two different planting densities for high speed sawmill markets. The difference between regimes is increased utilization of sawtimber volume because of slightly better tree form at higher density.

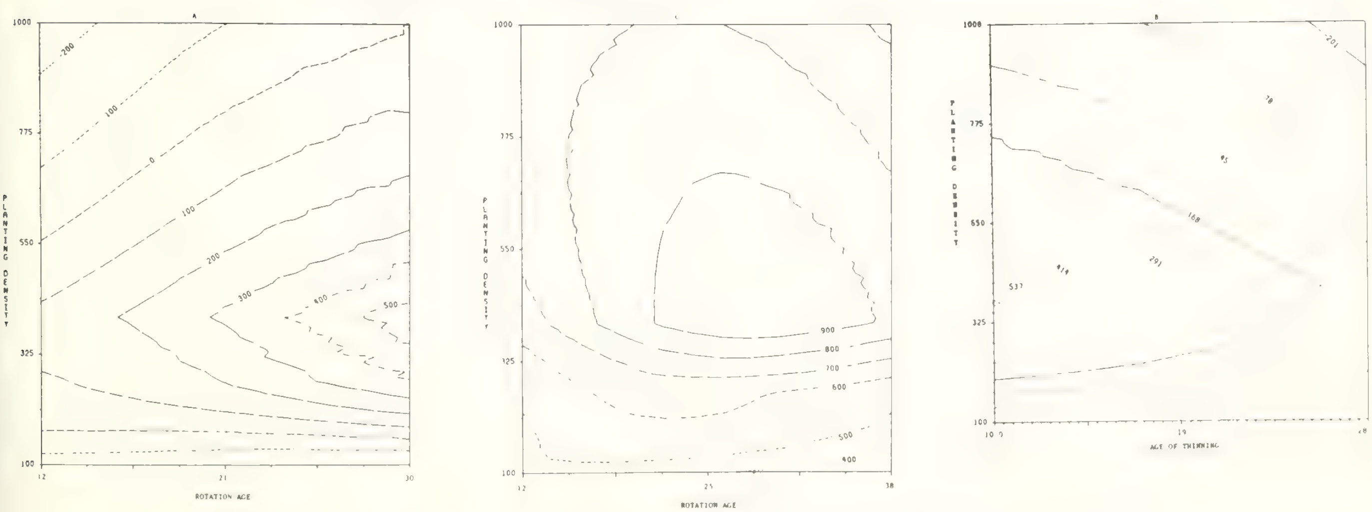

Figure 5.--Soil expectation value as a function of planting density, rotation age, and thinning age for HSS (a and b) and MIX (c) price functions.

value loss at low planting densities. This results in the low density optimum, found in Case 9, being eliminated in Case 11.

CONCLUSION

Each market price function leads to a distinct optimal stand management regime. Constant price functions result in high planting density and short rotations for loblolly pine. Size sensitive price functions result in low planting density and relatively short rotations. Size and quality sensitive price functions result in moderate planting density, a late thin, and late harvest.

The effect of stand density on lumber yield by grade needs further research. The importance of quality on optimal stand management has been demonstrated in this paper, but only for a hypothetical case.

It has been demonstrated here that at current prices of crude oil, OSB has a competitive advantage over solid wood products for a company which produces its own wood. While this could lead to a conclusion that raw wood quality has decreasing significance as a factor in forest management, one must weigh the expectation for future crude oil prices. As a nonrenewable resource, the long term relative price trend can only be up. Leading to an eventuality of OSB losing its competitive advantage over solid wood products. Wood quality may become even more important than it is today. So, given today's markets, management practices should allow for a different market in the future. Obviously, if we knew the future markets for raw wood products, forest management would be far easier.

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APPENDIX A

General Operational and Economic Assumptions

Interest rate (real) 4%
Fixed harvest cost \$37.50/acre

Variable logging cost	<7"	8"	10"	12"	14"	16"	18"	20"	25"	30"
\$/cubic foot	.34	.27	.23	.20	.18	.17	.16	.15	.14	.14

Transportation cost for 25 miles .... \$0.10/cubic foot
Thinning cost was 53% more than harvest cost
Site preparation cost \$78.00/acre
Variable planting cost \$0.10/seedling
Sawtimber minimum diameter .... 8 inches
Oriented stand board minimum diameter .... none

Site index (base 25) 65

Growth and yield predictions--whole stand diameter/height distribution model for managed loblolly pine--Hafley and Buford (1985).

Row thin every 5th row (remove 20% of basal area) then selection thin remaining stand by removing a variable amount.

Oriented strand board price function (Deal 1986)

1985 cost of resin and wax in output units \$27.00/Mft2
1985 cost of resin and wax in input units \$0.19/ft3
Wood value at the mill
1985 costs of resin and wax \$1.12/ft3
Wood value at the mill
double resin and wax costs \$0.93/ft3
Wood value at the mill
triple resin and wax costs \$0.74/ft3

High speed sawmill price function (Deal 1986)
(Scraggsaw and headsaw carriage operation)

Variation 1) No adjustments due to density/quality interaction
Value at the mill dbh < 15 inches

$$\text{value\$/ft3} = (-1.97818 + 0.890627 * \text{dbh}(1/2) + 0.0018964 * \text{height})$$

$$\text{dbh} \geq 15 \text{ inches}$$

$$\text{value\$/ft3} = (1.36 + 0.0018964 * \text{height})$$

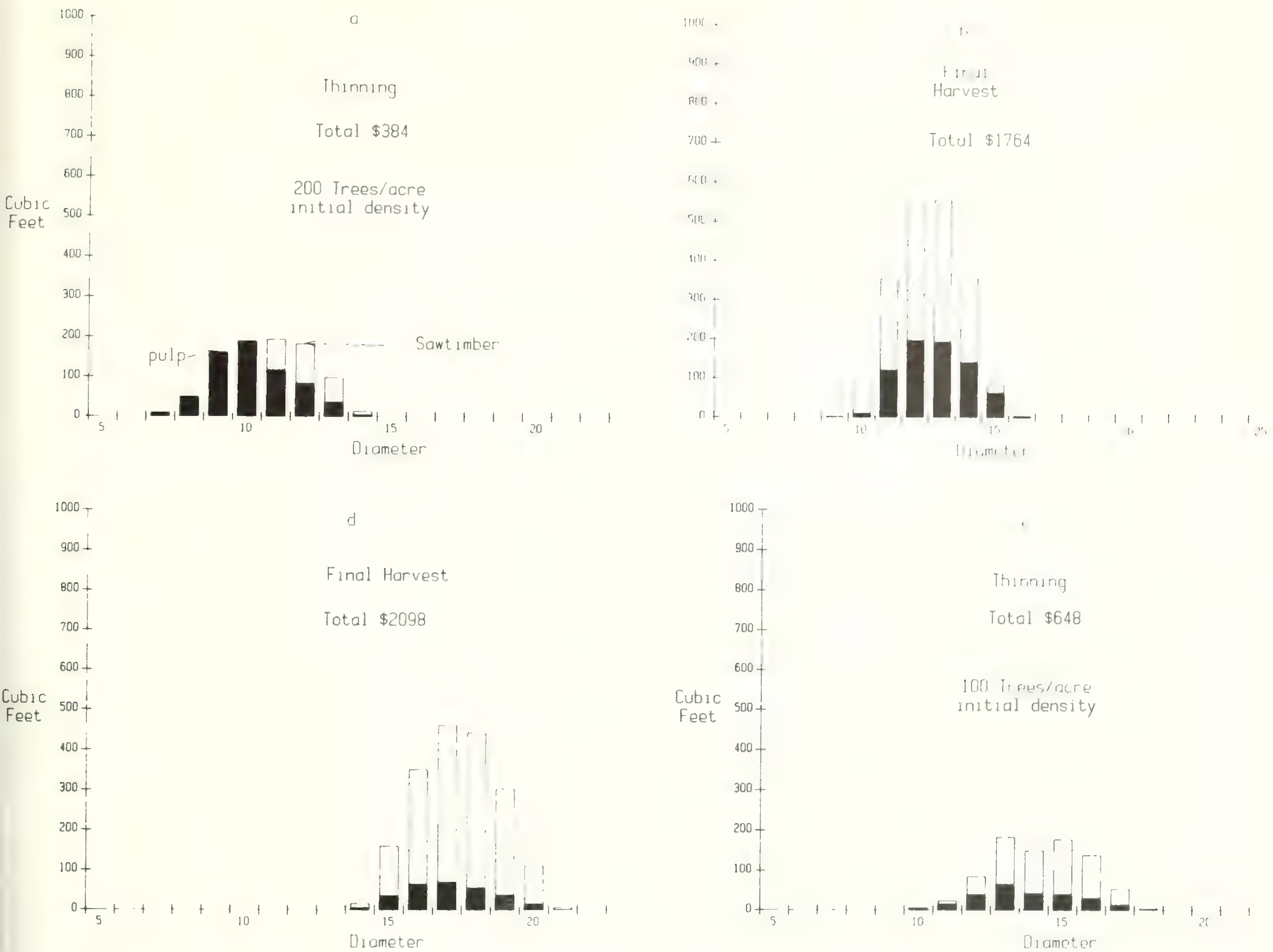


Figure B1.--Diameter distributions at thinning and harvest for two different planting densities and a MIX price function with no price deductions for quality loss.

Variation 2) Only wood below live crown can be used as sawtimber.

Use same function as above for all wood below live crown.

Crown ratio (CR) was calculated as a function of initial spacing (S) and age (A).

$$CR = 2.73986 + 261.398/A + 3.4022 * S - 0.0770436 * A * S$$

At time of thinning CR was calculated using the above equation, at final harvest CR was calculated using either the CR at thinning or the above equation at harvest, which ever estimate for highest crown.

Variation 3) As initial planting density decreases, sawtimber loses quality, therefore value, at a constant rate. Use same functions as above except with the addition of the following value reduction function (R).

if planting density $\geq$ 400 trees/acre then R = 1 (no loss)

if planting density between 100 and 400 trees/acre then

$$R = 0.0033 * (\text{Planting Density}) - 0.33$$

if planting density $\leq$ 100 trees/acre then R = 0 (no value left)

Due to a lack of experimental data this function is hypothetical.

Combination or mixed market price function

This price function assumes that the above two raw wood markets exist equal distances from the stand. The tree is merchandised and allocated to the market of highest value.

APPENDIX B

Crown ratio relation used:

$$CR = 2.73986 + 261.398/AGE + (3.48022 - 0.0770436 * AGE)\ Spacing$$

where CR is the average stand crown ratio

AGE is stand age.

Spacing is the initial tree spacing in feet.

Figure B1 shows the crown ratio relation for five different initial tree spacing.

Efficient Optimization of An Individual Tree Growth Model

Atsushi Yoshimoto, Gonzalo L. Paredes V., J. Douglas Brodie[1]

Abstract.--The PATH algorithm (Paredes and Brodie 1987) is interpreted by means of the calculus of variations. Using the PATH algorithm, a new dynamic programming model called Stand Optimization System (SOS) is developed. The system is incorporated into a growth simulator constructed by Arney (1985). Further limitation of optimality on the PATH algorithm and the relationship between the Lagrange multiplier and the decision variable are discussed.

Determination of the optimal thinning regime and rotation age has been a main problem in even-aged forest stand management. The widespread application of operations research techniques has been contributing to solving the stand level optimization problem. The dynamic programming approach has been developed and extensively applied in recent years.

The dynamic programming approach was applied to the forestry field by Amidon and Akin (1968), Arimizu (1959), and Schreuder (1969). Early scientists used a two-descriptor, i.e., volume and age, dynamic programming model in order to cluster each state (Brodie et al. 1978, Chen et al. 1980, Kilkki and Vaisanen 1970). Brodie and Kao (1979) proposed a three-descriptor dynamic programming model (number of trees, basal area, and age), using an existing stand growth simulator for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) called DFIT.

This three-descriptor dynamic programming model with forward recursive approach has been extended and adapted for other decision variables and species. Riitters et al. (1982) presented a dynamic programming model with timber production and grazing control joint optimization using a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) growth model called PPINE. Haight et al. (1985) proposed a dynamic programming model with thinning and rotation age optimization using lodgepole pine (*Pinus contorta* Doug. ex Loud.). A hardwood release and thinning optimization dynamic programming model was constructed for loblolly pine (*Pinus taeda* L.) by Valsta and Brodie (1985). Torres (1987) proposed a thinning optimization dynamic programming model for a *Pinus hartwegii* growth model. In comparison with the above three or more descriptor models, a dynamic programming model optimizing both thinning and rotation age for an individual-tree red pine model (*Pinus resinosa* Ait.) was completed by Martin and Ek (1981) with two descriptors.

Although some of the above models reduced calculation effort to select the optimal activity by using the "neighborhood storage location" technique (Brodie and Kao 1979), dynamic programming still has computational limitations. The more complicated the growth simulator, the more memory and calculations are required (Hann and Brodie 1980).

Paredes and Brodie (1987) resolved the memory and calculation problem by utilizing both network theory and the theory of the Lagrange multipliers. Their efficient way of selecting the optimal path reduced the number of calculations and associated computer storage in comparison with the traditional dynamic programming approach. Since the number of elementary calculations in traditional dynamic programming increases exponentially with problem size, the efficiency is greater with larger problems. However, searching for the optimal value of the Lagrange multiplier remains incomplete. Two other problems called trade-off problems were not dealt with by Paredes and Brodie (1987), one of which deals with situations where no thinning is applied at a certain stage, and the other of which deals with problems associated with insufficient look-ahead period when intensive thinning is applied.

This paper describes and interprets their algorithm (called the PATH algorithm) from a different point of view, in which the technique does not use the Lagrange multiplier. Then a new dynamic programming model is proposed by using the PATH algorithm and a growth simulator called Stand Projection

[1] *Yoshimoto and Brodie are Graduate Assistant and Professor, Department of Management, Oregon State University, Corvallis, OR 97331. Paredes V. was Graduate Research Assistant, Department of Forest Management, Oregon State University, and is currently Instructor, the University of Austral of Chile.*

System (SPS) (Arney 1985). The trade-off problems are also solved by a new algorithm called Multi-Stage PATH (MSPATH).

OPTIMIZING FORMULATION

The PATH Algorithm by the Lagrange Multiplier Approach

Paredes and Brodie (1987) proposed the optimization problem with the Lagrange multiplier as follows:

$$\max f_N(Y_N) = \sum_{n=1}^{N} A_n(T_n) + \sum_{n=1}^{N} \mu_n[X_n - T_n + G_{n+1}(Y_n)] \quad [1]$$

where A_n is the return from thinning, Y_n is the stand volume after thinning, X_n is the stand volume before thinning at stage n, G_{n+1} is growth from stage n to stage n+1 based on Y_n, and μ_n is the Lagrange multiplier at stage n. They modified the formulation in the dynamic programming problem as:

$$f_n(Y_n) = \max_{[T_n]}[A_n(T_n) + \mu_n[X_n - T_n + G_{n+1}(Y_n)]] + f_{n-1}(Y_{n-1}) \quad [2]$$

The PATH algorithm does not utilize the state variables of the growth model for storing the optimal residual stand at each state with a fixed Lagrange multiplier, so that computational task was vastly diminished.

Searching for the optimal level of $[T_n,\mu_n]$, this objective function can be optimized. If the dimensions of both the first term and the second term on the right-hand side of equation [2] are monetary units, the Lagrange multiplier, μ, can be interpreted as the price per unit of resource including its growth potential. In physical objective examples, the Lagrange multiplier can be estimated as simply 1. The control decision concerns both the direct return from the thinning and the return from the future stand. Although it is possible to guess the Lagrange multiplier, it is not always guaranteed that such a value is optimal. Then it is necessary to search for the optimal Lagrange multiplier. The difficulty of searching for the optimal Lagrange multiplier μ_n, can be eliminated by the following procedure.

The PATH Algorithm by the Calculus of Variations

The total return $V(t_n)$ at stage n (time t_n) is the summation of marginal return over time:

$$V(t_n) = \int_{t_0}^{t_n} M(t)\, dt \quad \text{in the continuous case,}$$

$$= \sum_{i=0}^{n} M(t_i) \quad \text{in the discrete case.} \quad [3]$$

where M(t) is the marginal return at time t. Once thinning, T, is implemented at stage 1 (time t_1), the objective function, $V(t_n)$ is divided into two parts as:

$$V(t_n,T) = \int_{t_0}^{t_1} M(t,T)\, dt + \int_{t_0}^{t_n} M(t,T)\, dt \quad [4]$$

The first integrand on the right-hand side is equal to the sum of thinning and residual stand after thinning at stage 1. The second integrand represents the sum of growth after thinning from stage 1 to stage n (time t_n). Therefore, $V(t_n,T)$ represents the sum of returns from both thinning at stage 1 and the future stand at stage n. If the optimal thinning regime is required, the objective function becomes:

$$V^*(t_n,T) = \underset{0<[T]\leq V(t_1)}{\text{maximize}}\ V(t_n,T)$$

$$= \max\{\int_{t_0}^{t_1} M(t,T)\, dt + \int_{t_0}^{t_n} M(t,T)\, dt\} \quad [5]$$

It is obvious that the first integrand on the right hand side is constant because the current thinning cannot affect the previous stand. Then equation [5] becomes:

$$V^*(t_n,T) = \underset{[T]}{\text{maximize}}\ V(t_n,T)$$

$$= V(t_1) + \max_{[T]} \int_{t_0}^{t_n} M(t,T)\, dt \quad [6]$$

This approach to interpretation of the PATH algorithm is one of the classical calculus of variations problems (Intrilligator 1971). The classical calculus of variations problem is to find the arc lying in a given plane and connecting two specified points in the plane by an arc of shortest length (Dreyfus 1965). Thus, in this context, the classical calculus of variations problem can be interpreted as that of choosing the optimal thinning strategy, which satisfies the boundary condition and maximizes the integral or summation objective functional, V(·).

Schreuder (1971) specified a problem of the optimal strategy for an even-aged forest in the calculus of variations. Although specifying a continuous problem, Schreuder (1971) turned the calculus of variations problem into a dynamic programming problem because when the necessary conditions for an optimum (Dreyfus 1965) were obtained for the general expression, a higher than first-order nonlinear differential equation, such as the Euler equation, resulted. Moreover, even if it could be solved, it would be necessary to investigate numerically all the roots to locate the global maximum because the conditions are only necessary and not sufficient. Then it was impossible for Schreuder (1971) to obtain a closed-form expression.

However, if we know exactly what the objective function looks like, then it is not necessary to solve the Euler equation to obtain a general solution. Furthermore, necessary conditions function as useful tests, which can eliminate candidate solutions, even if they are not sufficient to prove global optimality. After satisfying necessary conditions, it becomes obvious that there is an optimal trajectory. If we have such a trajectory that satisfies a given problem, that trajectory could be optimal.

Let the objective be the maximization of total volume, J, i.e.,

$$\max_{[X]} J = \sum_{n=0}^{N} \int_{t_n}^{t_{n+1}} X'_n \, dt \qquad [7]$$

$$X = (X_0, X_1, X_2,,, X_N) \quad X_{N+1}(t_{N+1}) = 0, \; X_0(t_0) = 0$$

where X is a vector describing a thinning regime.

As mentioned by Everett (1963), if the value of X_i is decided independently in each cell, the sum is obviously maximized by simply maximizing the following objective function with respect to X_n, so that we solve recursively:

$$\max_{[X]} J_n = \max_{[X]} \int_{t_n}^{t_{n+1}} X'_n \, dt \qquad [8]$$

In the PATH algorithm, it is assumed that the choice of X_i does not affect the optimal path after the next stage, which is equivalent to the above assumption. The reason is that the stand, which provides the maximum sum of marginal return, or growth during the previous period, seems most likely to create the optimal stand at the next stage. However, there is a case where this assumption does not hold. Such a case is discussed later.

In a given problem, for any $X_n(t)$ satisfying boundary conditions, all necessary conditions provided by Dreyfus (1965) hold. Thus what should be done next is to search for the optimal trajectory among admissible ones. Let's define notation as follows:

Y_n = vector describing the stand at stage n before a decision T_n,

X_n = vector describing the stand at stage n after a decision T_n,

T_n = vector describing the decision variable (thinning) at stage n, transferring the stand X_n into Y_n,

X'_n = stand growth at range (t_n, t_{n+1}).

Therefore, among these variables, some relationships are formulated:

$$X_n + T_n = Y_n \qquad [9]$$

$$X_n + \int_{t_n}^{t_{n+1}} X'_n \, dt = Y_{n+1} \qquad [10]$$

From these equations, the objective function [8] can be converted into the following function:

$$\begin{aligned} \max_{[X_n]} J_n &= \max_{[X_n]} \int_{t_n}^{t_{n+1}} X'_n \, dt \\ &= \max_{[X_n]} \{Y_{n+1} - X_n\} \qquad [11] \\ &= \max_{[T_n]} \{Y_{n+1} - X_n + T_n\} \end{aligned}$$

Since Y_n is constant for all admissible trajectories [the principle of optimality, Dreyfus (1965)], Y_n can be eliminated from the objective function, resulting in the new objective function:

$$\underset{0<T_n<Y_n}{\text{maximize}} \; J_n = Y_{n+1} + T_n \qquad [12]$$

As a result, a sequence of T^*_i which optimizes the objective function [12] in each cell, can constitute the optimal thinning regime maximizing the original objective function [7]. It is also possible to determine the optimal rotation age in terms of maximizing mean annual increment of J with respect to t_{n+1}. In other words, setting up the maximax problem as:

$$\max_{[N]} \max_{[T]} \frac{1}{t_{N+1}} \sum_{n=0}^{N} \int_{t_n}^{t_{n+1}} J(X_n, X'_n, t) \, dt \qquad [13]$$

the optimal rotation age can be obtained at the same time. If the optimal stand at each stage is obtained, equation [13] becomes:

$$\begin{aligned} &\max_{[N]} \max_{[T]} \frac{1}{t_{N+1}} \sum_{n=0}^{N} (Y^*_{n+1} + T^*_n - Y^*_n) \\ &= \max_{[N]} \frac{1}{t_{N+1}} (T^*_1 + T^*_2 + \cdots + T^*_N + Y^*_{N+1}) \qquad [14] \end{aligned}$$

where Y^*_{N+1} and T^*_n (n=1,2,,,N) are the optimal stand volume at age t_{N+1} and optimal thinning level at age t_n, respectively.

Given prices of inputs, outputs, and an appropriate discount rate, the production function can be converted into a net revenue equation where revenues and costs occurring at different points in time are properly discounted. Maximizing this expression yields the optimum patterns of inputs and outputs through time.

Limitation of the Optimality

In the PATH algorithm, it has been assumed that the optimal path at every stage is determined based on evaluations of the stand's reaction at the next stage. In other words, the return from

the future stand is estimated on the basis of the next stage. Then the path provided is optimal as long as it is decided on this criterion, and also if necessary conditions for an optimum, from the calculus of variations problem, hold. However, two interesting situations can develop. The first situation occurs if there is no thinning at the next stage. The second situation occurs in conjunction with intensive thinning, when the look-ahead period is insufficient to evaluate impacts on the future stand. These situations are discussed below.

The Impact on Optimality With no Thinning at the Next Stage and Intensive Thinning at the Current Stage

Let's consider the first situation, at which it is assumed that T_1 at stage 1 is the optimal thinning level on the basis of stage 2, and that there is no thinning at stage 2 based on stage 3. Thus, if sufficient evaluation of the future stand based on stage 3 is done at stage 1, there can be another optimal thinning level, T'1. If T'1 produces more objective value than the path provided by the PATH algorithm, the trade-off has to be evaluated at stage 3.

As for the second situation, it is possible for a stand with few trees to create a great potential growth over the long-term in a complicated stand growth simulator. This discrepancy also violates the assumption of the PATH algorithm that one-stage look-ahead period is sufficient to evaluate impact of the future stand. Then sufficient evaluation of the future stand should be implemented especially for a complicated growth simulator. These two situations suggested the following new PATH algorithm called Multi-Stage PATH (MSPATH) algorithm.

Multi-Stage PATH (MSPATH) Algorithm

The above two situations occur when the look-ahead period is insufficient to evaluate impact on the future stand. The MSPATH algorithm uses each possible look-ahead period at each stage in order to search for the optimal objective value at each future stage based on the different combinations of look-ahead period. In other words, the MSPATH algorithm searches for the optimal combination of look-ahead period from the initial stage to the final stage at the same time when the optimal thinning level is decided. Then MSPATH can decide where one-stage look-ahead is used, two-stage look-ahead is used and so on, and how much the optimal thinning level is for the optimal combination of look-ahead period. Then the optimal thinning regime at each stage can be obtained based on multi-stage look-ahead period. Figure 1 shows the possible combinations of look-ahead period by the MSPATH algorithm.

From the viewpoint of computational burden, MSPATH creates more computation than PATH. However, if the traditional dynamic programming algorithm is used in order to solve the same optimization problem as MSPATH by using SPS, the problem of insufficient look-ahead period also appears. That is,

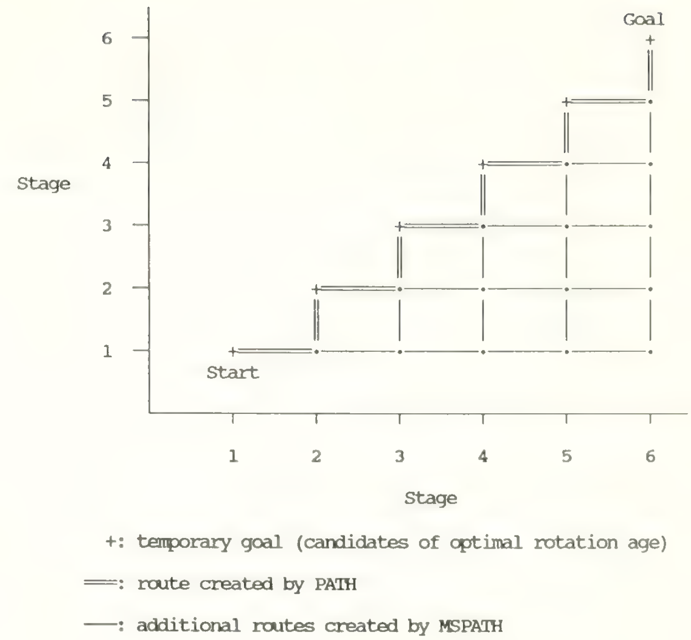


Figure 1.--Possible routes by MSPATH.

with the traditional dynamic programming algorithm, a one-stage look-ahead period, is utilized. Therefore, if a more accurate solution is needed for the traditional dynamic programming algorithm, the same technique as MSPATH utilizes to extend look-ahead period should be implemented. As a result, even if MSPATH creates more computational burden than PATH, it is still efficient in comparison with the traditional dynamic programming algorithm, and provides the optimal solution so long as necessary conditions for a calculus of variations problem hold.

STAND OPTIMIZATION SYSTEM (SOS)

By using the SPS growth simulator (Arney 1985), the Stand Optimization System models (SOS) are proposed with either the PATH algorithm or the MSPATH algorithm. The acronym SOS is used to distinguish the proposed optimization framework from the SPS simulation framework.

The SOS system developed here is classified as a deterministic, single descriptor, discrete-state, discrete-stage dynamic programming model. The problem solved utilizes a forward recursion. While searching for the optimal thinning level at each stage, it is possible for the user to use one of two different criteria in order to select the optimal thinning level.

One of them is such that once the objective value declines, the previous thinning level is labelled optimal. The other is such that after calculating all admissible solutions, the optimal thinning is selected among them. The following procedure is imbedded into the SOS model with the PATH algorithm. Since the basic procedure for the SOS model with the MSPATH

algorithm is the same as the SOS model with PATH, optimization procedure discussion is excluded for the MSPATH algorithm here.

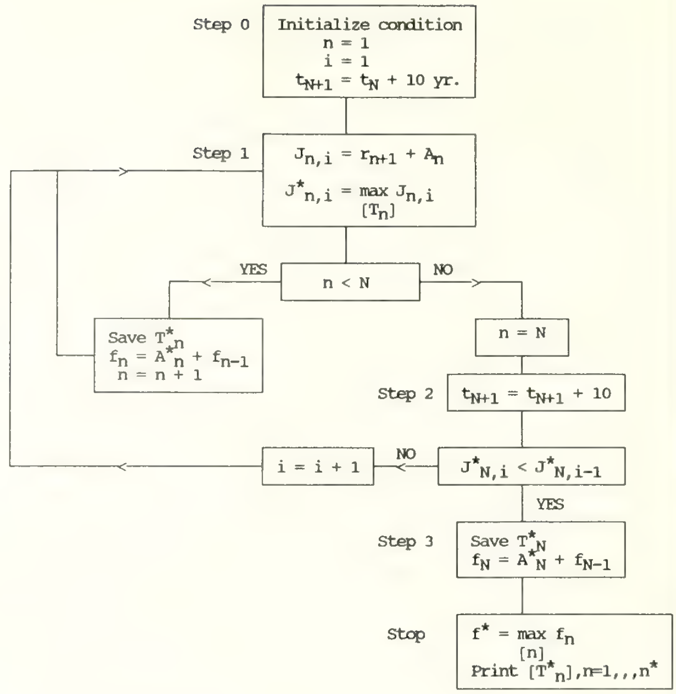
Optimization Procedure

Employing a forward recursion to find the optimal thinning regime and rotation age, SOS searches for the optimal thinning regime at each stage in the following way:

First SOS creates the initial forest stand structure having diameter distribution with individual tree height data and crown ratio data, which result from a yield table given by the user. After thinning an amount of trees, which is decided by the number of iterations calculated, and the interval of node given by the user, i.e., N x Interval, a residual stand grows until the next stage. At this stage, the sum of returns from both thinning and the future stand is compared with the previous one to store the best thinning level so far. If the user selects the first option, i.e., the unimodality assumption, once the objective function declines, SOS quits the iteration at this stage, and decides the previous thinning level is optimal. Otherwise, the iteration is continued until the number of the residual trees is less than the interval of thinning, then the best thinning level among admissible strategies is selected. SOS can also select the optimal thinning method at each stage among thinning from below, thinning from above, and thinning to a cut/residual ratio fixed as 1.

If the thinning method "joint optimization" is selected by the user, after storing the best thinning level for one method at each stage, SOS does the same operation for two other methods so as to search for the best thinning level with each method at each stage. Comparing these three best objective values at each stage provides the optimal thinning method and level at each stage.

After determining the optimal trajectory at this stage, SOS sets up the initial forest structure at the next stage. Iterations continue over state and over stage until the last activity completes searching for the optimal trajectory from the initial stage to last stage. At the last activity, SOS searches for the optimal thinning level and rotation age at the same time by means of increasing rotation age by a 10-year step. In other words, first set rotation age 10 years after last activity, store the best objective value and thinning level. Then add 10 years to the previous rotation age, search for the optimal objective value, then compare the present best value to the previous one. If the previous one is greater than the present one, the previous age is regarded as the optimal rotation age after all activities. However, it is possible for the early stage to have more objective value than the rotation age selected by the above procedure. That is, the above procedure provides the optimal rotation age if the optimal rotation age is later than the last thinning time given by the user. Then SOS searches for the new optimal rotation age again from the initial stage to the rotation age calculated by the above procedure. As a result, optimization of both thinning regime and



r_n : return generated by residual stand at stage n before a decision

R_n : return generated by residual stand at stage n after a decision

R'_n : sum of marginal return generated by residual stand from stage n to stage n+1 after a decision T_n

A_n : return generated by a decision at stage n

f_n : total return at stage n

N : last stage

Figure 2.--Flowchart of the PATH algorithm.

rotation age is completed. This procedure is summarized in figure 2.

Features of the SOS Model

The objective function of SOS can be based on mean annual increment of basal area, total cubic feet, merchantable cubic feet or board feet as well as present net worth (PNW), and soil expectation value (SEV).

Combining thinning basis, such as trees per acre (TPA) or crown competition factor (CCF), and thinning method, such as thinning from below, thinning from above, or thinning to a c/r ratio of 1, can provide 2 x 3 = 6 possible thinning regimes. If thinning method joint optimization is selected, SOS indicates not only the optimal thinning level but also the optimal thinning method at each stage on either TPA or CCF basis.

For the sake of making the model simple, cost and revenue from thinning and final harvest are based on entry cost, stumpage price premiums, and other constant silvicultural costs. Entry cost is fixed over time for thinning and final harvest. Price

equation per cubic foot is expressed as a function of DBH, which can be created by using either one linear equation or an equation with several continuous linear segments. It is also possible to utilize a different price equation for different species. These financial data, with interest rate, are utilized for economic optimization and in the financial reports of physical optimization. Although it is possible to use more complicated economic data, such as logging cost identical for each thinning level, cost is limited as above.

Since a price equation transforms a searching surface which is directly derived from physical data into a new surface which has economic information, it is necessary to take into account what kind of price equation can be used. In other words, even if the searching surface obtained from direct physical data is nicely concave, it is possible for it to become an irregular surface when the price equation is included. In such a case, one of the necessary conditions, the Weierstrass condition, which shows the condition for concavity over the control variable (thinning level), would be violated, as well as the Weierstrass-Erdman corner condition. For example, if a step-wise price equation is used, these conditions are not satisfied. This violation is shown by the relationship between the objective function and the decision variable, which would not be concave. Once these conditions are violated, the solution provided by SOS becomes the better solution, and not the best one.

ANALYSIS WITH THE SOS MODEL

Illustrative Example

To demonstrate SOS with both the PATH and MSPATH algorithms, an input file and financial data are required. Characteristics of the data are:

species: Douglas-fir and western hemlock,

site index: 82 of Douglas-fir at 50-year breast-height-age basis,

region: Pacific Northwest Region.

Thinning is implemented at age 20, 30, and 40 years. The basis of thinning is number of trees per acre, and the type of thinning is thinning from below with maximum DBH limit 100 inches (this value should be large so that thinning from below can be implemented at every diameter class).

In addition to this data, tree height, number of trees per acre, breast height age, and percent of crown ratio at each DBH class as well are given in table 1. Also optimization basis, interval of node, and financial data are provided as follows:

optimization basis: soil expectation value(SEV),

interval of node: 20 trees per acre,

interest rate: 4%,

entry cost: $50.00,

Table 1.--An illustrative example (Arney 1985).

	sp	st-id	age	region
Stand	DF	82	10	PNW
Merch	1.0	16.4	5.0	9.0
Name		An illustrative example		

	age basis			method		
Thinning	1	20	1	0	1	100
Thinning	1	30	1	0	1	100
Thinning	1	40	1	0	1	100

Table	SP	DBH	HT	TPA	BT-AGE	CR
1	WH	2	18	15	19	80
2	WH	3	27	92	19	80
3	WH	4	32	227	19	80
4	WH	5	35	121	19	80
5	WH	6	36	41	19	80
6	DF	3	30	32	18	80
7	DF	4	34	57	18	80
8	DF	5	38	138	18	80
9	DF	6	38	72	18	80

Clump	0.85						
Reports	10	20	30	40	50	60	70

coefficient for reducing thinning value: 0.80,

regeneration cost: $200./acre at age 0,

price/1,000 ft^3: 200xDBH + 80,

As shown in table 2, if all activities are required, the optimal thinning regime and rotation age from the PATH algorithm are:

thinning 180 trees per acre at age 20,

thinning 160 trees per acre at age 30,

thinning 60 trees per acre at age 40,

clearcut at age 50.

However, the results from the MSPATH have different thinning levels at each stage depending upon the temporal rotation age, which is characterized by MSPATH. Figure 3 shows the optimal path from the PATH algorithm in terms of stand volume and figure 4 shows the path from the MSPATH algorithm. Figure 5 shows the searching surfaces over time, which can reveal the actual optimal rotation age. According to figure 5, 30 years is the optimal rotation age for both models, which can differ depending on the economic data.

As expected, however, the difference of the objective value between the PATH algorithm and the MSPATH algorithm is less than 2%, so if the user does not care about this small difference, the PATH algorithm can be recommended to save computational time.

Table 2.--Optimal thinning regime.

	Temporary rotation age									
	20 years		30 years		40 years		50 years		60 years	
AGE	PATH	MSPATH	PATH	MSPATH	PATH	MSPATH	PATH	MSPATH	PATH	MSPATH
20*	702**	702	180	180	180	280	180	360	180	280
30			522	522	160	--	160	--	160	--
40					362	422	60	--	200	340
50							302	342	--	--
60								162	79	
SEV	3268	3268	3644	3644	3457	3555	3108	3179	2762	2799

**Thinning age.*

***Trees per acre.*

-- = no thinning.

SEV = $ per acre.

Relationship Between the Lagrange Multiplier and Optimal Thinning Regime

As mentioned before, the PATH algorithm can be expressed in terms of the Lagrange multiplier as:

$$f_n(Y_n) = \max_{[T_n]}[A_n(T_n) + \mu_n[X_n-T_n+G_{n+1}(Y_n)]] + f_{n-1}(Y_{n-1}) \quad [2]$$

at the n-th stage. The PATH algorithm is also interpreted from a different point of view as:

$$J_n = \max_{[T_n]} [A_n(T_n) + r_{n+1}(Y_{n+1})] \quad [15]$$

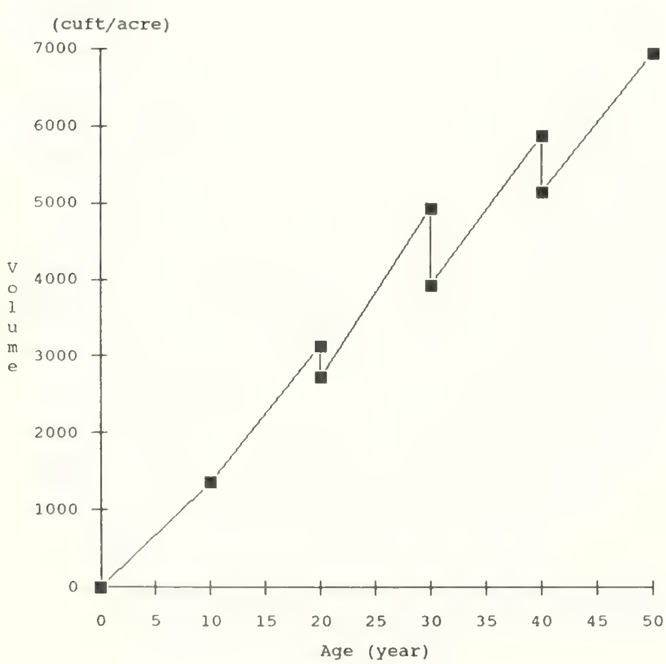


Figure 3.--Optimal thinning regime by the PATH algorithm.

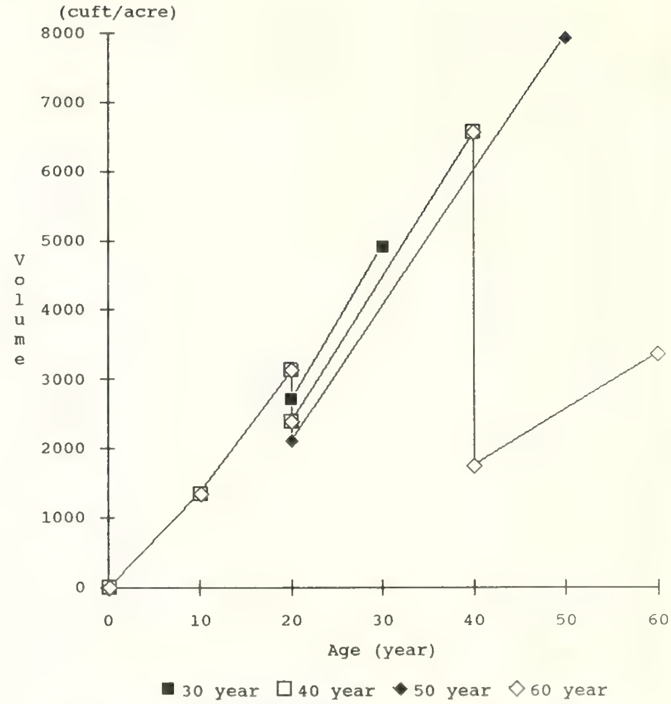


Figure 4.--Optimal thinning regime by the MSPATH algorithm.

Since this objective function does not have the Lagrange multiplier, it is possible to estimate the Lagrange multiplier. Suppose that necessary conditions for a calculus of variations problem hold and sufficient look-ahead period is used. Then if the optimal solution is obtained by the above two functions respectively, the optimal thinning levels obtained by these two methods should coincide as long as the same interval of node is used. Then at the optimal point the following equation is satisfied:

$$A^*_n(T_n)+ \mu^*_n[X_n-T_n+G_{n+1}(Y_n)] = A^*_n(T_n)+r^*_{n+1}(Y_{n+1}) \quad [16]$$

Solving for the Lagrange multiplier μ^*_n, we can obtain:

$$\mu^*_n = \frac{r^*_{n+1}(Y_{n+1})}{X_n-T_n+G_{n+1}(Y_n)} \quad \frac{r^*_{n+1}(Y_{n+1})}{Y_{n+1}} \quad [17]$$

Therefore at the optimal point of the n-th stage, the Lagrange multiplier can be interpreted as the average return per unit volume at the (n+1)-th stage. If the basis of optimization is cubic-foot volume, the Lagrange multiplier becomes equal to 1 as was expected by Paredes and Brodie (1987).

Economically speaking, both the Lagrange multiplier and the decision variable correspond with each other. In other words, if the Lagrange multiplier is given, then the decision variable is determined at the optimal point. Then searching for the optimal allocation is limited to the range at which this relationship holds.

Figure 6 shows the relationship between the Lagrange multiplier derived from equation [17] and the decision variable,

thinning level. The higher thinning level, the larger the Lagrange multiplier. Also the greater the stage, the less the Lagrange multiplier.

The Lagrange multiplier derived is interpreted economically not only as the shadow price or the opportunity cost but also as the marginal value per unit volume of resource at each stage by which the maximum attainable value of resource could be increased if an additional unit of resource were to become available (Dorfman 1961, Paredes and Brodie 1987). According to equation [17], the Lagrange multiplier having the above interpretation at each stage should be estimated based on the future stand, not the current.

CONCLUSIONS

The objective of this paper was to develop a new dynamic programming model using the SPS growth simulator (Arney 1985), employing the PATH algorithm (Paredes and Brodie 1987). This model called SOS can optimize both thinning regime and rotation age based on either mean annual increment of the given physical basis, present net worth, or soil expectation value, as long as necessary conditions for a calculus of variations problem hold and one-stage look-ahead period is sufficient to evaluate the future stand. Once either one of these conditions is violated, or one-stage look-ahead period is insufficient, the solution obtained by PATH becomes the better solution, and not the best solution. Then SOS based on the MSPATH algorithm is also proposed in order to solve the optimization problem when one-stage look-ahead period becomes insufficient in evaluating the return from the future stand. However, once a necessary condition is violated, the solution provided by MSPATH becomes better, and not best.

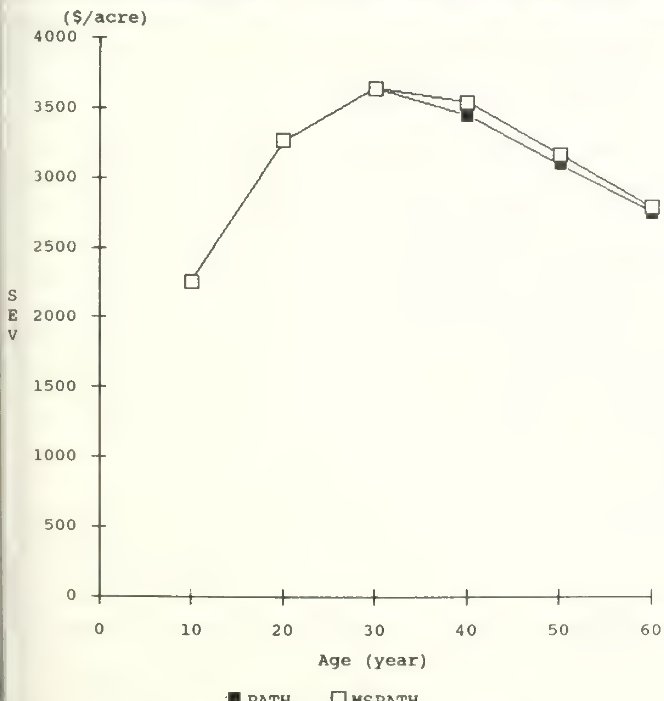


Figure 5.--Searching surface of SEV.

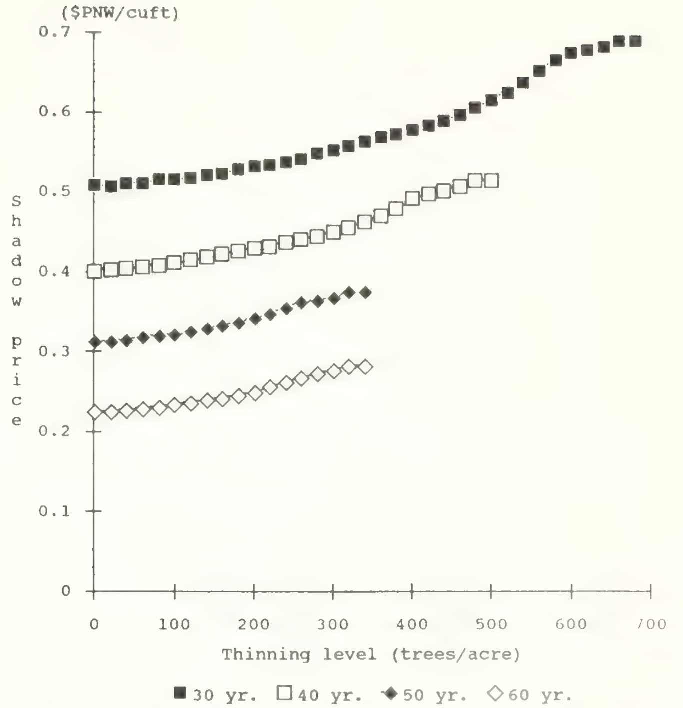


Figure 6.--Relationship between shadow price (Lagrange multiplier) and thinning level.

The modification of the PATH algorithm by the calculus of variations in order not to use the Lagrange multiplier allows one to recognize the efficient PATH algorithm easily. Once the optimal resource allocation is obtained, the optimal value of the Lagrange multiplier can be calculated automatically as well, in terms of the relationship between the objective function with the Lagrange multiplier and without.

Directly treated as a decision variable, the unit thinning level given by the user determines the number of iterations at each stage, or the residual level before thinning divided by the unit thinning level. This technique eliminated so many calculations that the joint optimization of thinning methods and the optimization of rotation age are completed with less computation in one run of SOS than the traditional dynamic programming algorithm. Thus the calculation task and memory required to store optimal stands is vastly diminished to utilize very complex forest stand level production models.

Brodie and Haight (1985) indicate that when thinning from above is incorporated in an optimization model, where growth is driven by top-height a violation of the principle of optimality can occur unless state space is expanded to include top-height. Although SOS growth is driven by top-height, the implied expansion of state space becomes unnecessary through the process of evaluating the future stand (after thinning from above) as part of the objective function. The same problem of suboptimization occurs, however, if the future stand productivity is not projected sufficiently forward. In such case, the MSPATH algorithm can resolve it.

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Concave vs. Convex Singular Path Solutions for Optimal Economic Thinning Schedules in Even-Aged Stands

Matthew T. Turner and David R. Betters[1]

Abstract.--Singular path solutions for economically efficient thinning schedules have been found to have both concave and convex shapes. A concave path indicates the rate of thinning increases with time; a convex path depicts the opposite. The results of this study indicate only convex singular paths should occur for most thinning situations occurring in even-aged stand management.

Optimal economic thinning schedules for even-aged stands have been derived using both dynamic programming and optimal control theory (OCT) techniques. In general, the optimal thinning policy may show the rate of thinning to increase as the stand ages (i.e., concave singular path) or decrease as the stand ages (i.e., convex singular path).

Several recent studies using dynamic programming show the optimal thinning policy to involve a decreasing rate of thinning as time progresses, thus mimicking a convex singular path (Amidon and Akin 1968, Brodie et al. 1978, Brodie and Kao 1979, Chen et al. 1980). Using OCT, Cawrse et al. (1984) and Donnelly (1986) derived convex time paths for thinning. On the other hand, Clark (1976) and Clark and DePree (1979) developed concave paths for the optimal thinning policy (fig. 1).

The purpose of this paper is to explore what factors might lead to convex versus concave singular path solutions for the optimal economic thinning problem. The study concentrates on comparing the OCT work cited above along with empirical analysis of similar formulations.

OCT Singular Path Solutions

In OCT a singular arc occurs when the Hamiltonian is linear in the control variable. The control (e.g., thinning harvest) is determined by the requirement that the coefficient of the linear terms remain zero along the singular arc (Bryson and Ho 1975). In the case at hand, the control variable for thinning is linear and the OCT approach does result in a singular path solution. Further, since the control is linear, the Euler-Lagrange condition from classical calculus of variations may be used to determine the singular solution (Pfaffenberger and Walker 1976). Clark (1976), Clark and DePree (1979), and Cawrse et al. (1984) all applied the Euler-Lagrange condition to determine the singular path. The formulations were similar in terms of the objective functional (present net value based on an infinite series) varying only by the state equations used for stand growth. Clark used a Gompertz function while Cawrse used a logistics function. Since this was the only key difference between the studies, our research effort focused on the growth functions influence on the shape of the singular arc.

The growth function, or state growth, for Clark's work was

$$\frac{dv}{dt} = at^{-b}ve^{-cv} - h(t)$$

where

- at^{-b} is a monotonically decreasing function of time which tends toward zero as the stand ages. It serves as a check on the growth, which without this function would always depict positive growth after thinning regardless of stand age,
- c is a coefficient,
- v is stand volume per acre,
- h(t) is the thinning harvest volume, and
- ve^{-cv} is the standard Gompertz function.

[1]Graduate Research Assistant and Professor, respectfully, Department of Forest and Wood Sciences, Colorado State University, Fort Collins, Colorado 80523.

And for Cawrse's work the growth function, or state equation, was

$$\frac{dv}{dt} = at^{-b}rv\left(1-\frac{v}{k}\right) - h(t)$$

where

r and k are coefficients,

$rv\left(1 - \frac{v}{k}\right)$ is the logistics function,

and all other terms are as defined previously.

Since these growth functions monotonically decrease with time, all singular paths must eventually decrease with time. However, the rate of the decrease may increase (concavity) or decrease (convexity) with time.

Application of the Euler-Lagrange condition to the objective functional with these state equations resulted in the singular path for Clark's work as

$$(1 - cv)\, e^{-cv} = \frac{1}{at^{-b}} \left[-\frac{\dot{R}(t)}{R(t)} + \alpha\right]$$

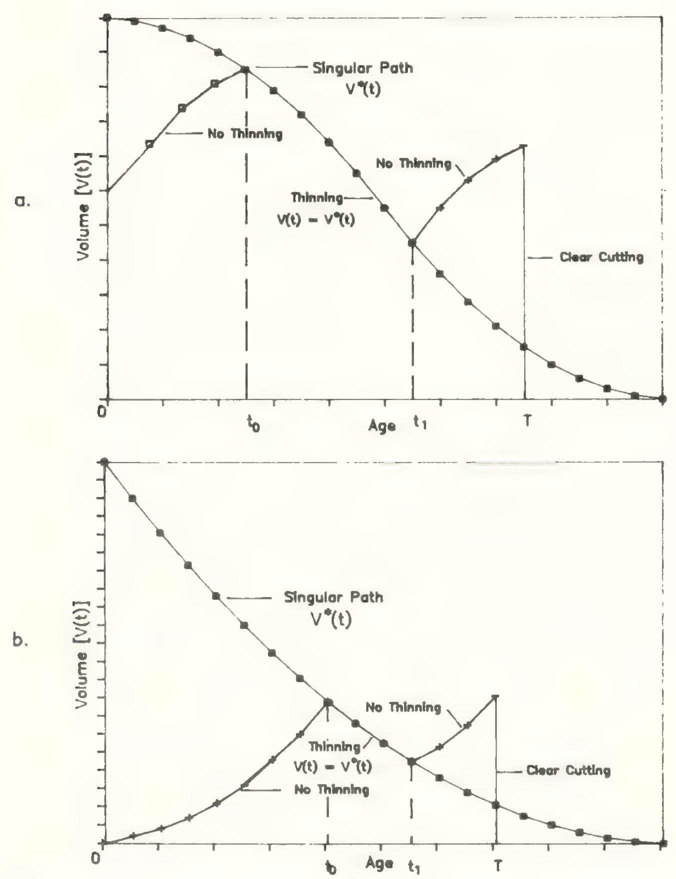

Figure 1.--Concave (Clark 1976) labeled "a," vs. Convex (Cawrse et al. 1984) labeled "b," singular path solutions where v is stand volume and t is time in years. Concavity is defined in relation to the graph origin or mathematically as $f[\theta t_2 + (1-\theta)t_1] \geq \theta f(t_2) + (1 + \theta) f(t_1)$ where f is the singular path, $t_1 < t_2$ are times, and $0 \leq \theta \leq 1$. For a convexity definition, the $\geq$ is changed to a $\leq$.

and the singular path for Cawrse's work as

$$V = \frac{k}{2} - \frac{k}{2ar} - \frac{1}{at^{-b}} \left[-\frac{\dot{R}(t)}{R(t)} + \alpha\right]$$

where

$R(t)$ is the net revenue from thinning at time t and $\dot{R}(t)$ its rate of change, and

α is the annual discount rate.

Numerical Analysis Solutions

There isn't any straightforward method to analytically determine whether the singular paths are concave or convex. Therefore, the singular path for Clark's work was derived using the Newton-Raphson algorithm (Burden et al. 1981). This algorithm uses the singular path function, its first derivative, and the Taylor expansion series to estimate values for the optimal path. The singular path values for Cawrse's work were developed using a computer spreadsheet program.

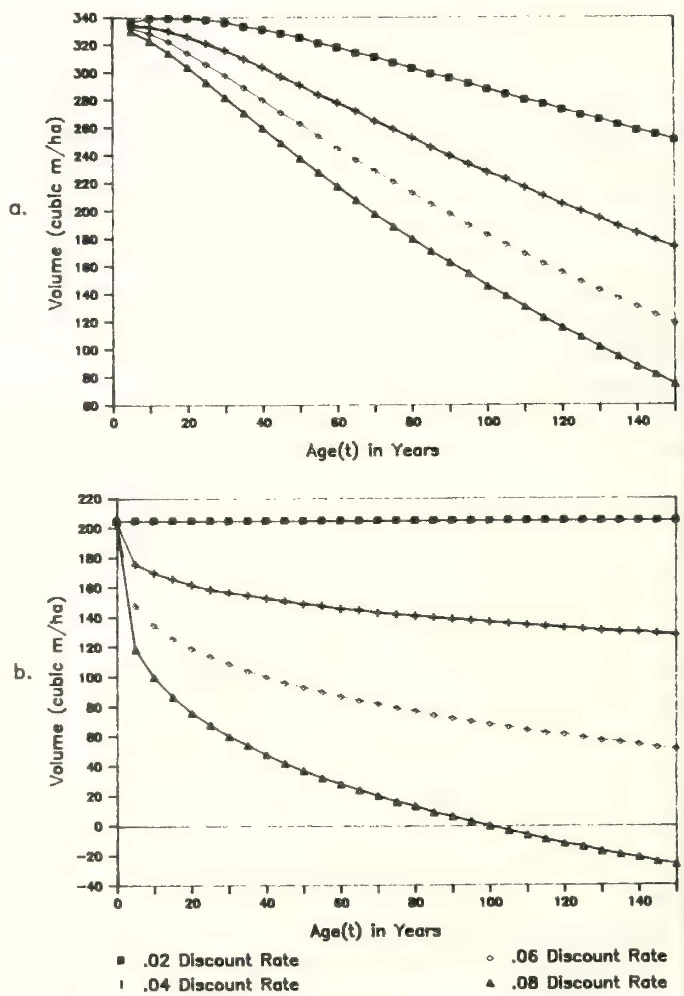

Figure 2.--Convex singular paths for Clark and DePree (1975), labeled "a," and Cawrse et al. (1984), labeled "b," data sets derived through numerical analysis.

In the initial analysis, the same growth and economic parameters used by Clark and Cawrse were applied to attempt to reproduce their results. In Cawrse's case, the paths derived were identical to those shown in that study. On the other hand, we derived convex paths for Clark's singular solutions rather than the concave curves reported in his work (fig. 2). After testing several combinations of growth and economic parameters, the singular solutions remained convex. The singular paths are not concave as Clark's studies suggest.[2] The question then arises whether or not convex paths are the general case for these type problems, or are they only the case for these two studies?

A second numerical analysis was made using a Gompertz equation with economic data from Kilkki and Vaisanen (1969) and using a logistics equation fit to net yield tables for lodgepole pine (Dahms 1964). In both cases, the numerical analysis again resulted in convex singular paths.

Conclusions and Implications

These empirical tests support the conclusion that the OCT singular path solutions to the even-aged thinning problem should generally be convex. This convexity should increase as the discount rate increases. Thus, as a general policy, if thinnings are to be applied in an optimal financial manner, the rate of thinning should decline over time and the growing stock become more stable as the stand ages (that is, until it is completely removed, normally via a clearcut). This policy is largely a consequence of higher thinning costs relative to the volume of growth and the increasing impact of the discounting factor as time passes.[3]

Many renewable resources follow growth patterns similar to that depicted by the growth functions used in this analysis. If the resource is renewed periodically, such as is the case for even-aged stands, and the economic relationships are similar, one might expect that convex singular paths would also describe the optimal economic policy for those cases.

As a practical tool, the family of singular path solutions can be used to help determine thinning rates and stocking levels for any given rate of return or where rates of return may change during the course of a stand's growth. For example, at any stand age, t, the stand stocking and estimate of the thinning rate for various discount rates, can be read directly from the graph of singular paths. As such, the curves do provide management guidelines for general thinning strategies.

Although these empirical results are not all encompassing, for most thinning situations commonplace to forestry, OCT optimal singular path solutions would appear to be convex in nature.

[2]A personal communication with Colin Clark indicated that errors in the application of the analysis package they used resulted in mistakes in numerical estimates of the singular path solutions. He confirmed the fact that their curves should be convex.

[3]The importance of discounting is emphasized by the fact that without discounting (i.e., discount rate of 0) the optimal policy is to not have any thinnings and to clearcut the stand when growth discontinues, i.e., when ddvt = 0.

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Optimal Stocking of Species by Diameter Class for Even-aged Mid-to-Late Rotation Appalachian Hardwoods

Joseph P. Roise, Joosang Chung, and Chris B. LeDoux[1]

Abstract.--Nonlinear programming (NP) is applied to the problem of finding optimal thinning and harvest regimes simultaneously with species mix and diameter class distribution. Optimal results for given cases are reported. Results of the NP optimization are compared with prescriptions developed by Appalachian hardwood silviculturists.

To achieve the desired objective from any thinning, it is necessary to regulate stand density, stand structure, stand quality, and species composition (Marquis et al. 1984). Consideration of all these variables simultaneously can represent a major computational challenge. However, several recent studies using nonlinear programming (NP) techniques appear to have overcome the computational limitations imposed by traditional optimization techniques. New perspectives on formulation and solution techniques have made simultaneous determination of optimal thinning plan, including timing, selection of species by diameter class, and rotation length, a tractable problem. Several recently published papers have explored these new perspectives. Roise (1986c) showed that the class of nonlinear programming algorithms referred to as nonlinear derivative free techniques can be used to optimize a wide variety of simulation problems, including optimal residual diameter class selections. Brooke et al. (1984) has reported significant progress in optimization of high level modeling systems using nonlinear programming. The optimization of simulation models is becoming more accessible.

The purpose of this paper is to present study results from an optimal species by diameter class stocking control problem. The optimal thinning plan and rotation length is solved for an Appalachian mixed hardwood stand using the MANAGE hardwood stand management simulator (LeDoux 1986a) incorporated into the Hook and Jeeves (1962) NP technique.

[1] *The authors are, respectively, Assistant Professor and Graduate Research Assistant, Department of Forestry, Box 8002, Raleigh, NC 27695, and Industrial Engineer and Project Leader, Northeastern Forest Experiment Station, USDA Forest Service, Box 4360, Morgantown, WV 26505.*

The following section briefly reviews the historical background on stand level decision makings. In the subsequent section, the general mathematical formulation for stand level decision makings is stated. Next, the model and the results of its application to a 1-acre Appalachian hardwood stand are described.

Background

As stated by Hann and Brodie (1980), stand level decision making involves such basic problems as finding the optimal species mix, planting density, thinning plan, fertilization plan, and rotation length. The literature indicates that most stand level optimization studies reduced the problem to simultaneously determining the optimal thinning regimes and rotation length. This reduction is probably because of the large number of variables necessary and the resulting computational burden when all variables are included.

Hann and Brodie (1980) further stated that nonlinear programming may have potential. The computational ability of several NP algorithms for even-aged stand management optimization have shown to be flexible optimization tools by Kao and Brodie (1980) and Roise (1984, 1986a). NP techniques have been used earlier to find optimal conversion strategies for uneven-aged stands (Adams and Ek 1974). Uneven-aged stand management has received a great deal of recent advance and clarification using nonlinear methods.

Haight (1987) has used the gradient projection method to solve uneven-aged stand management problems. Haight and Getz (1987) used a penalty function and gradient nonlinear

programming method to compare optimal transition harvest regimes with either fixed end point or equilibrium end point constraints. They solve for the species composition and stand structure which optimize transition regimes and steady state condition. They conclude that solving for an optimal steady state and then solving for the optimal transition to that steady state will in general find suboptimal regimes when compared to solving for a more general equilibrium endpoint and transition regime simultaneously. Bare and Opalach (1987) used a direct search, derivative free, constrained nonlinear programming algorithm to solve for the optimal sustainable equilibrium diameter distribution and species mix in distance independent individual tree growth model.

For even-aged management, NP has not received as much attention. Kao and Brodie (1980) used a "modified flexible polyhedron method" to solve for the optimal thinning plan and rotation length. It is a modification of the simplex method of Nelder and Mead (1964) for constrained nonlinear programming. They also made a comparison between NP and DP by solving the same example problem with both techniques.

Roise (1986a) compared three NP techniques and discrete DP. The three NP techniques were the simplex method of Nelder and Mead, Hook and Jeeves' method, and Powell's method, all of which are derivative free multidimensional optimization techniques for unconstrained problems. He applied three different techniques to an example stocking control problem. He observed that the Hook and Jeeves' method performed better than others with regard to the relative computational efficiency and robustness of convergence for the given example.

Roise (1986b) applied Hook and Jeeves' method to solving for optimal thinning regimes including optimal diameter class distribution. The following section briefly describes his unconstrained objective function derivation procedures. Two advantages of this formulation in increasing the computational efficiency of Hook and Jeeves' method were observed: (1) the separable functional form of the dynamic stocking control was well suited for coordinate optimization and (2) empty diameter classes reduced the number of active variables to be evaluated.

Mathematical Programming Formulation

The mixed species forest stand management problem can be formulated in terms of timing and intensity of thinnings and final harvest.

$$\text{Max } f(t_j, X_{ijn}, t_{T+1}) \qquad [1]$$

subject to

$$X_{ijn} \in \Omega \qquad i = 1,2,\ldots,N$$
$$H_{ijn} >= X_{ijn} \qquad j = 1,2,\ldots,T$$
$$t_j, X_{ijn}, H_{ijn} \geq 0 \qquad n = 1,2,\ldots,S$$

where N is the number of diameter classes per species; S is the number of species; T is the number of thinnings; f is the objective function; X_{ijn} is the amount of timber to remove from diameter class i and species n at thinning j; H_{ijn} is the amount of species n in diameter class i at thinning j, $H_{ijn} = g[(H_{k(j-p)n} - X_{k(j-p)n}, t_j]$, $p = 1,2,\ldots,j-1$, $k = 1,2,\ldots N$, where g is a growth and yield model with decision variables of size class thinning intensity by species and interval between thinnings; Ω represents the operational constraints of the production system; t_j is the time between thinning j-1 to j; and t_{T+1} is the elapsed time between the last thinning and final harvest.

Assuming that there are no external production constraints, the number of decision variables required is TNS+T+1. The number of decision variables represents the maximum possible problem size. This will be discussed in more detail later when discussing problem reduction.

In order to solve problem [1] using Hook and Jeeves' method, the formulation is transformed into an unconstrained objective functional form as outlined by Roise (1986a). The transformed formulation is

$$\text{MAX } f(t'_j, r'_{ijn}, t'_{T+1}) \qquad [2]$$

where t'_j, r'_{ijn}, and t'_{T+1} are transformed decision variables t_j, X_{ijn}, and t_{T+1}, respectively. This unconstrained function can be solved by any unconstrained optimization technique including Hook and Jeeves' method. Formulation [2] can be interpreted as a barrier function. This formulation enables simultaneous optimization of the time of thinnings, amount of trees to remove for each diameter class by species, and rotation length.

Optimization and Simulation Model Description

All optimization procedures have two parts: the optimization algorithm and the system model. Hook and Jeeves' algorithm and the MANAGE stand management simulator are the two parts used here. Hook and Jeeves' algorithm controls the iteration processes to reach a local optimum point by adjusting decision variables. It is not within the scope of this article to discuss how to determine the global optimum, which is known as an unsolvable problem using NP when the system model is nonconvex. The system model, MANAGE, evaluates the decision variables passed from the Hook and Jeeves' algorithm and passes back an evaluation of present net worth.

MANAGE is a complete management systems simulator for mixed hardwood stands. It consists of a stand growth and yield simulator, GROW (Brand 1981), a thinning and harvest production estimator, ECOST (LeDoux 1985), a tree conversion model, BUCKING (Ledoux 1986b), and economic analysis model, PNW (LeDoux 1983). It includes a number of options which reflect various management activities in the real world. Only the PNW objective function option is used. The decision variables from the Hook and Jeeves' algorithm, the removal ratio of all species by diameter classes and thinning times, are passed to MANAGE. MANAGE removes the specified number of trees for each class, bucks the stems, and estimates present

net value according to log grade values and net conversion costs. The estimated PNW for each entry is summed and passed to the Hook and Jeeves' algorithm where it is considered an objective function valuation, given decision variables.

The Hook and Jeeves' algorithm is illustrated in figure 1. The algorithm searches for the local optimum with a two step method: exploratory and pattern searches. Exploratory searches are directional steps along all coordinate axes from a fixed point, called the "base point." When exploratory searches are completed for all directions, the function gradient is estimated and the search continues in that direction. This movement along the gradient is called a "Pattern Search." The two step searching method is repeated until all the exploratory searches fail to improve the objective value. After successful searches for time variables or pattern searches, the stand conditions are stored for the next iteration to take advantage of dynamic stand structure. If an exploratory search fails, the step size is reduced by some percent of previous step size. It iterates until the step size decreases below a set tolerance. At this time, the last base point is reported as the local optimal solution.

Application to Example Stand Problem

Data from an example 1-acre stand was provided from the USDA Forest Service (Morgantown, WV). The example stand is 70 years old with site index 70. Average stand d.b.h. is 13.3 inches. The stand has 135 trees composed of multiple species such as basswood, hardmaple, white oak, red oak, beech, yellow-poplar, cucumbertree, and other minor species. Among the species, the first four species are considered economically valuable and others less so. The economically less important species were grouped as "Other Hardwoods" for the analysis. A total of 31 species, including "Other hardwoods," are appeas-

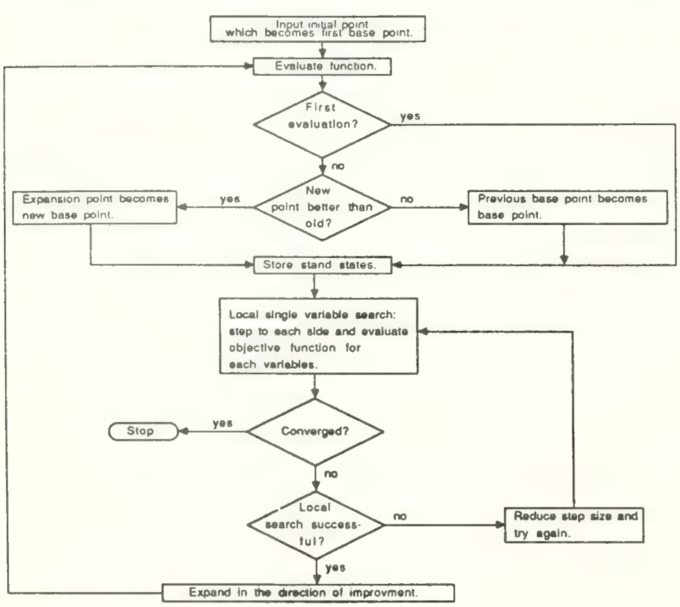


Figure 1.--Flowchart of the Hook and Jeeves' method.

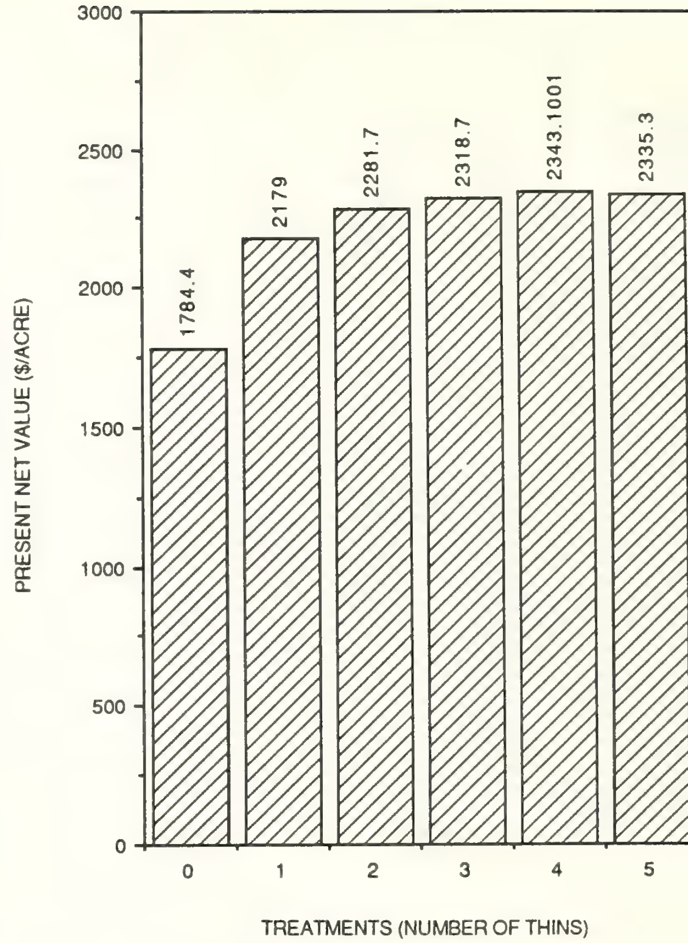


Figure 2.--Comparison of best local optima found with 0 to 5 thinnings.

able. The initial stand structure at age 70 is shown in figure 4 a diameter distributions by species. Real annual interest is assumed to be 4%. The Ecologger I skyline yarding machine is th logging option used.

The objective is to maximize PNW with decision variable of timing and intensity of thinning and final harvest. Th number of species, the number of diameter classes, and th number of thinnings determine the total number of decisio variables required. In this example, the initial stand has species, including "Other hardwoods." Twenty five 2-inc diameter classes per species are used. This allows for al possible growth projections, as it turns out only 15 diamete classes were needed. At this age, precommercial thinning is no an option. Starting from zero thinning, we increased the numbe of thinnings by one in each subsequent run until the peak of th local optimal point is recognized (fig. 2). Results are summarized in table 1.

Each number of thinning type was solved three times wit different randomly selected initial points (matrix of decisio variables). All other non-control parameters remain fixed When one or more thinnings are involved, the three run converge on separate local optimum. This is an expected resul

Table 1.--Summary of results from three different initial points for six different numbers of thinnings.

No. of thins	Initial point $/ac	PNW $/ha	NFE	Local optimal $/ac	PNW $/ha
0	1780.6	4398.1	6	1784.4	4407.5
0	751.9	1857.2	15	1784.4	4407.5
0	321.9	795.1	18	1784.4	4407.5
1	1092.6	2698.7	821	2179.0	5382.1
1	1004.2	2480.4	1321	2166.9	5352.2
1	1384.7	3420.2	1550	2124.0	5246.3
2	1294.6	3197.7	1035	2281.7	5635.8
2	830.2	2050.6	1347	2234.6	5519.5
2	1448.9	3578.8	1421	2261.8	5586.6
3	1407.9	3477.5	1319	2318.7	5727.2
3	1510.9	3731.9	1584	2318.6	5726.9
3	1543.0	3811.2	1124	2309.5	5704.5
4	1390.4	3434.3	1992	2343.1	5787.5
4	1231.9	3042.8	2598	2315.1	5718.3
4	1081.0	2670.1	2267	2232.0	5513.0
5	1217.9	3008.2	2095	2335.3	5768.2
5	1380.3	3409.3	1517	2307.4	5699.3
5	1047.3	2586.8	2167	2309.8	5705.2

if the objective function is nonconvex (Roise 1986a). Nonconvexity results among other reasons from sigmoidal individual tree growth functions, discrete thinning events, and nonlinear tree value functions (Roise 1986b). NP techniques may or may not provide a global optimum for nonconvex problems. By comparing several runs starting from different points, we may find the best optimal solution. However, the global optimum can never be guaranteed in solving nonconvex problems.

The best optimal solution from zero to five thinnings are compared in figure 2. Objective value reaches a peak at four thinnings and then decreases at five thinnings. When there are five thinnings, one thinning time interval goes to zero in two of the three runs from different initial points. This indicates that for those two, five thinning initial points, the local optima found has only four thinnings.

The number of functional evaluations (NFE) is used as a measure for the computational efficiency. The total NFE required generally increases as the number of active variables increase because more exploratory searches are required. Moreover, different initial matrices of decision variables can results in wide fluctuation of NFE, since some may start much closer to the optimum than others. Figure 3 illustrates the convergence rates of all 15 runs, when the number of thinning is greater than or equal to one. NFE ranges from approximately 800 to 2,598 according to the number of thinnings and the initial matrix of decision variables. In general, 90% of a local optimum PNW is reached within 25% to 30% of total NFE.

The number of decision variables represents the problem size. The problem size was reduced greatly by taking advantage of empty diameter classes as specified by Roise (1986b). The NP algorithm searches only in the vector space of active

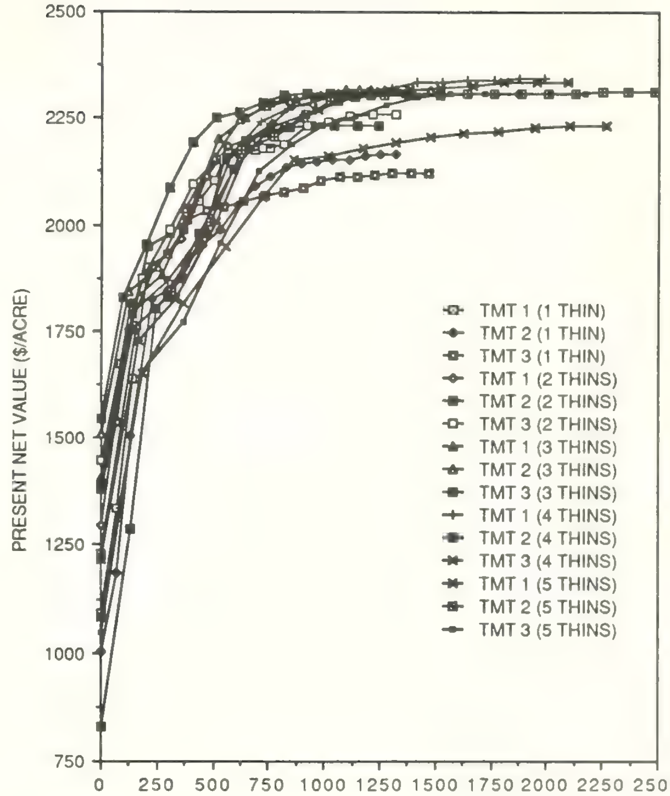


Figure 3.--Convergence rates for treatments from different initial points.

variables. As shown in table 2, the number of active variables was only 18% to 28% of the total variables for treatments with more than two thinnings. This reduction is related to the number of occupied diameter classes in the initial stand structure, the growth rate of species on the stand, and harvesting practices. The ratio of active to total variables for a Douglas-fir stand was observed to be approximately 0.3 by Roise (1986b).

For illustration, the results of the example problem, stand structure by species over time, are shown in figure 4. This was the best optimal solution for all 19 runs. Thinning entries occur at age 70, 90, 120, and 150 and final harvest at age 160. In general, trees are removed from the upper diameter classes. The discrepancy between the number of residual trees of a graph and

Table 2.--Reduction of the number of variables.

No. of thins	Total no. of variables	Aver. no. of active var.	Ratio
0	1	1	1.00
1	77	46	0.60
2	253	70	0.28
3	379	86	0.23
4	505	99	0.20
5	631	109	0.17

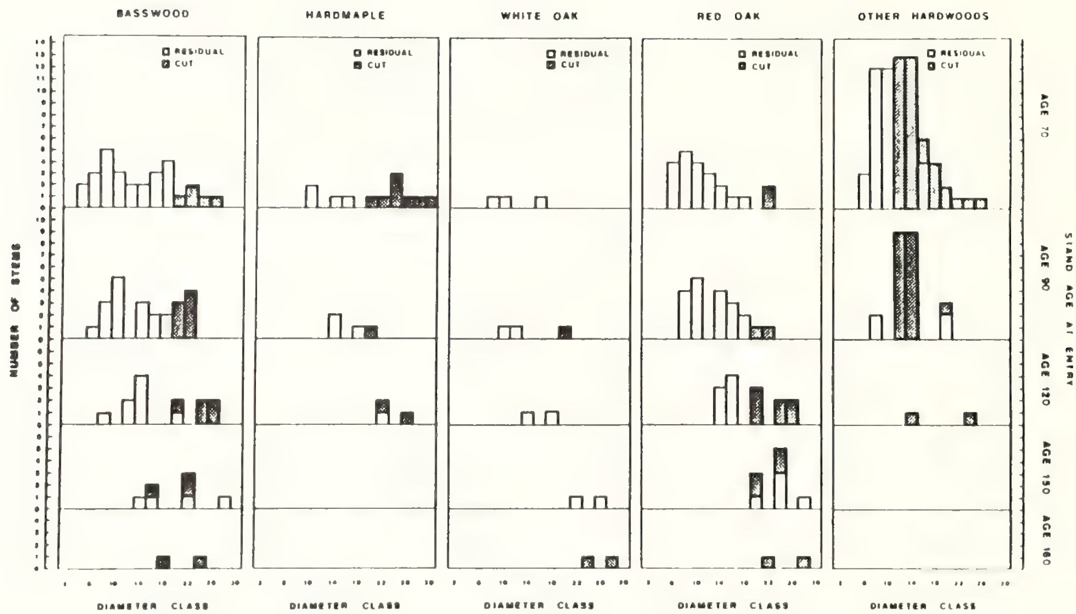


Figure 4.--Diameter class distribution before and after each thinning and final harvest.

the total number of stems in next graph is caused by mortality during that growth period.

How do these results compare to what a silviculturist would prescribe for the stand? To examine this question, we used the method of the prescribing silvicultural treatments in hardwood stands of the Alleghenies which Marquis et al. (1984) developed. Comparison is made on results from their method with results from our method for the first thinning. It should be noted that there is a major difference in objective between the two sets of results. Our objective is to maximize present net value of the stand explicitly considering expensive cable logging technology and detailed stump-to-mill costs. The silvicultural objective is to maximize the net undiscounted value of the stand.

> "Our guidelines on financial maturity are based on studies of individual tree financial maturity in New York, Pennsylvania, and West Virginia (Grisez and Mendel 1972, Mendel et al. 1973), plus unpublished results of computer simulator runs in Allegheny hardwood stands of varying species composition. Financial maturity of the stands in these computer runs was defined as the culmination of mean annual increment in dollar value. No interest rates or present net worth calculations were involved." (Marquis et al. 1984)

The method prescribes the distribution of cuts summarized in table 3 and illustrated in figure 5.

As can be seen, our method cuts trees exclusively from large diameter classes, whereas the silvicultural method prescribes cutting over all diameter classes, except in the sapling classes where both methods prescribe no cutting. In describing a commercial thinning, Marquis et al. (1984) state that trees should be removed primarily from the smallest and largest sizes, retaining those that are inbetween since these are the ones increasing most rapidly in value as they grow into size class they qualify for grade 1 sawtimber or veneer. Our method ignores the smaller sizes and increases cutting in the large to medium sizes. However, it should be noted that our method concentrates the first thinning on removal of low value species from the overstory and only cuts high value species with diameters greater than 20 inches. This is in agreement with the prescription developed using Marquis et al. (1984).

Our method also prescribes a much more intensive thinning than the silviculturists': residual basal area of 53 vs. 92 square feet per acre. There are several reasons for this difference. Our method cuts a much higher amount than what the silvicultural method prescribes because of inventory holding costs and expensive skyline cable stump-to-mill costs that must be offset

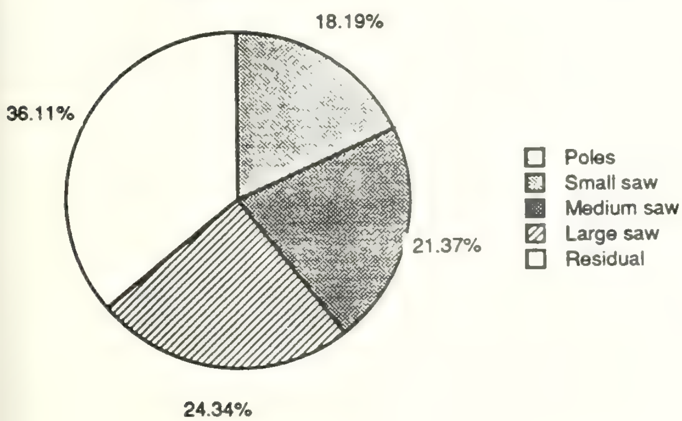
Table 3.--Comparison of results between methods of Marquis et al. and Roise et al. (basal area, ft²/acre).

Size class	Original stand	Cut	Residual stand	Cut	Residual stand
		Marquis et al.		*Roise et al.*	
Saplings	0.2	0.0	0.2	0.0	0.2
Poles	21.2	21.2	0.0	0.0	21.2
Small saw	50.1	5.0	45.1	26.9	23.2
Med. saw	40.5	12.2	28.3	31.6	8.8
Large saw	36.0	18.0	18.0	36.0	0.0

at each thinning. However, silviculturists are quick to point out that reducing a hardwood stand to such a low density will lead to problems later: lower tree quality, increased understory of interfering plants, and increased wind damage. Epicormic branching, forking, and other detrimental effects or costs may become serious at relative densities below 60% or 70%.

In general, thinning tends to increase competing understory and may lead to regeneration difficulties later in the rotation.

Roise et al.



Marquis et al.

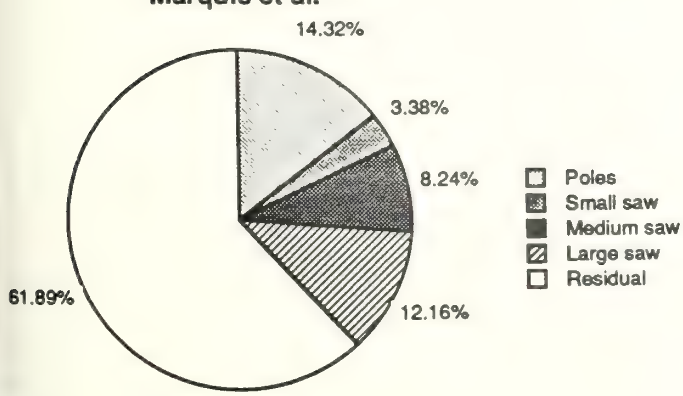


Figure 5.--Relative log size class distributions by Marquis et al. and Roise et al.

Intensive thinning opens a stand up to wind pressures which the root system cannot immediately absorb. This increases risk of windthrow in the stand. In the paper by Roise (1988), found in this same volume, the importance of stand quality is shown. Three stand parameters--volume production, tree size, and quality--are shown to control optimal stand management. All of the above factors are reasons cited by silviculturists not to have low residual densities. The results from the two methods are different because they have different objectives, they use different growth estimation routines and they have different assumptions on logging technology.

Conclusion

The typical Central Appalachian hardwood stand is a complex mixture of species and sizes. The problem of finding the optimal species mix by diameter class over time has a large number of variables. The use of the empty diameter class concept reduces number of variables and enables more efficient solution of the problem. Knowledge of desired species and diameter class structure is indispensable for foresters to make sound stand management decisions. This technique can be used to gain such a knowledge.

In this study, we expand the application of the Hook and Jeeves' method to multiple species problems. The solution to the stand management problem for multiple species stands are obtainable. As the numbers of active variables increase, the NFEs required to converge increase rapidly as well. Use of empty diameter classes and dynamic structures will reduce NFE and computer expense.

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General Analysis and Project Identification in National Forest Planning: A Discussion

Thomas R. Mitchell[1]

Abstract.--Site-specific analysis of Forest Plan direction is often done during implementation through various methods of "area analysis" or "implementation schedules." Such ground truthing of results from general analysis follows a traditional planning pattern. However, Forest Planning is a departure from such traditional planning. Thus rather than a separate, post planning analysis, it may be both appropriate and possible to accomplish more site specific identification of projects during Forest Planning. A discussion of accomplishing this type of analysis while also meeting the more general analysis requirements of Forest Planning is presented.

Context

Forest Planning--

- what is it?
- what is it suppose to accomplish?
- are concepts underlying more traditional analyses such as timber harvest scheduling appropriate?
- what level of detail should be included in analyses supporting Forest Plans?
- what level of detail should be included in the Plans themselves?
- is there a more efficient way to structure a FORPLAN model?
- what enhancements in analysis tools appear appropriate?
- is Forest Planning so different than anything that we have done in the past that it requires abandonment of procedures and concepts that were used successfully in the past and the development of new procedures and concepts? If so, what are these new concepts and/or analysis procedures?

Each of us comes to this meeting with our own answers to these questions, whether or not we have ever consciously addressed them. As you answer these for yourself, bringing to bear your own unique knowledge, skills, and experiences, each of you will have very different answers than anyone else. If each of us has a different perception of what the "problem" is, how can we discuss or evaluate the effectiveness of basic analysis procedures, and/or enhancements to those procedures to solving the "problem." It would appear that there is a need to discuss what the "problem" is that Forest Planning is attempting to solve as a initial step in discussions of ways to efficiently and effectively perform appropriate analysis.

I believe that such a dialogue was begun by Margo Garcia in her paper at the last Systems Analysis Symposium (Garcia 1985). I would like to use her paper as a basis for this paper. However, rather than dealing with a discussion of general planning theories, I have chosen to explore a definition of the analysis problem posed by Forest Planning in context of timber analyses required as part of Forest Planning.

In this exploration, three interrelated points are discussed. First is that timber analyses necessary to support Forest Planning are more comprehensive than analyses included in conventional timber harvest scheduling. Second, because of this, there is a need to shift from a mixed scanning viewpoint for planning and analysis to a systems approach (Garcia 1985, Mitchell 1975, Mouzelis 1968). And third, even though the same analysis tools can be used, this shift in the frame of reference for analysis requires different modeling/analysis techniques than conventionally applied.

Background

For almost 400 years, timber analysis and implementation of results of analysis appear to have followed a mixed scanning

[1] *Planning Staff Officer, Shoshone National Forest*

approach. That is, a high level decision based on analysis is made regarding the amount of volume or acres to be harvested in a time period and then field managers use this as a guide for implementation. This pattern appears to have begun as early as the mid 1500s with the development and publication of a model for forest management in a forest management text. That model is a "normal forest" which contains three components:

1. A normal (or even) distribution of age classes;
2. Normal stocking in each stand; and
3. Normal growth for the Forest as a whole.

This model describes a forest condition/dynamic equilibrium state that if achieved and maintained through time will yield a maximum, sustained flow of sawtimber. It was developed as a model for management of forests in order to meet needs of society for sustained production of wood products.

As foresters armed themselves with this model or goal, they went out to manage forest lands. In every case, the lands they came to manage were not organized/regulated to match the condition defined as a normal forest. So they had to develop a management scheme and guides to move a forest from its current condition toward the desired condition.

Development of a management scheme and guides appears to have been split into two distinct pieces. One piece focussed on the second and third parts of the "normal forest" description and developed silvicultural guides for stocking control as well as normal volume and yield tables. A second group concentrated on developing procedures/analysis techniques to guide movement toward and then maintenance of an even distribution of age classes. This second problem is often referred to as calculation of the allowable cut or now, in the U.S. Forest Service, calculation of an allowable sale quantity (ASQ).

Application of results of these two parts of the problem appears to have been accomplished in two sequential steps. First, the timber planner/analyst calculates an ASQ for a forest. This ASQ then becomes a guide (and more recently a target) for field managers. The task of the field manager is to identify stands to be harvested that will meet the ASQ. Guidance for this selection is provided by silvicultural guides for stocking control and biological growth of stands (i.e., from volume and yield tables/models and field inspection, the field manager can identify which stands "need" treatment the most and concentrate on those stands for production of the ASQ).

This splitting of the problem of achieving a normal forest into two parts has a number of implications. First, it allowed development of specialized skills and techniques for each part. In other words, some could concentrate on improving estimation of ASQs while others concentrated on techniques for identifying stands "ripe" for treatment as well as harvest design or layout. A problem that can and has arisen is that there is often a conflict between the calculated ASQ volume and the amount that "should" be harvested from a strict silvicultural standpoint.

Secondly, this splitting of the problem appears compatible with a mixed scanning approach to planning and management. When faced with a complex problem, a mixed scanning approach calls for a "high" level decision for guidance of management; e.g., calculation of an ASQ. In this decision making, not all complexities of the problem need to be addressed; e.g., there is not a need to have detailed stand by stand information. Rather, such detail is assumed to come to play during implementation of the decision. In other words, field managers take into consideration the conditions of candidate stands for harvest and attempt to meet the ASQ in a feasible way based on this more specific information. Whether or not application of mixed scanning was a conscious decision, this approach appears to describe traditional modes of operation in timber management.

Third, because the problem was split in terms of specialized knowledge as well as between forestwide ASQ calculations and implementation through application of a mixed scanning approach, those involved in calculation of ASQs could easily overlook questions of how their solutions would be implemented. Calculation of an ASQ is not an easy task. Each stand on a forest has a unique mix of location, cover type, age, site productivity, possible response to silvicultural practices, and stand condition. Because there are literally thousands of stands on any forest, detail on each stand would overwhelm any attempt at calculating an ASQ. When faced with overwhelming detail and complexity, a good analysis rule is to develop simplifying assumptions, estimate a solution, attempt implementation, and then modify the solution through time as necessary because of problems of implementation. A major simplifying assumption that appears to have been accepted in most, if not all, procedures for calculation of an ASQ is to ignore questions of how the solution will be implemented or even if it can be implemented.

Calculation of an Allowable Harvest Level/Allowable Sale Quantity

Simplification of the problem for calculation of an allowable sale quantity has taken on a number of forms over the last 400 years. Up until the last 30 to 40 years, such calculations were done through application of simplified formulas referred to as "area methods" or "volume methods" (Davis 1954, Iverson and Alston 1986). These relied on use of forestwide information including such items as total number of timbered acres, rotation age, and/or estimates of inventory and annual growth. The hypothesis that these rely on simplified assumptions and their results merely estimations appears born out by the fact that no two of these methods will provide the same answer for the same forest. In times where there is at least a perceived shortage of timber volume; when estimates are used as "hard targets" for performance measures of forest managers; where there is a perceived need for tieing budgets and accounting of those budgets in terms of production; and/or when there are other considerations (such as road construction or multiple-use production considerations), such crude estimates of an ASQ is at least perceived as less than satisfactory.

Over the past 30 to 40 years, there have been attempts at developing more precise and/or accurate estimates of an ASQ. This has not been without controversy and in fact some of these efforts appear to have been made in response to controversy. A major point of this paper is that these efforts have focussed almost exclusively on how to become more efficient/precise in calculation of an ASQ and have continued the trend of ignoring problems related to implementation. Further, this result was not based on a conscious decision, but rather is the result of attempting to efficiently resolve a selected part of a problem in context of an assumed historic mixed scanning mode of operation. And finally, the assumption that solutions can be implemented results in analyses procedures which are inappropriate for accomplishing timber analyses supporting Forest Plans for National Forests.

A precursor to linear programming models for calculation of an ASQ appears to have been a procedure referred to as a "tabular method" (Davis 1954). The simplifying assumption of a tabular method is that an ASQ can be calculated using information represented by forestwide timber strata. Each strata is assumed to be homogeneous in terms of cover type, age, productivity, and perhaps response to silvicultural treatments. These strata can then be listed on a spreadsheet by age class for a forest. The timber planner/analyst projects volume and growth by strata by time period (normally a decade), as well as identifies the number of acres of particular strata that would be harvested in each decade. Guidance for which strata to harvest is based on silvicultural considerations, as well as the need to move toward the desired age class distribution described by the normal forest model. Total harvest volumes are tabulated for each decade and compared with those from preceding decades in an attempt to move toward the desired age class while producing a non-declining flow of volume.

Calculation of an ASQ in this manner is labor intensive and may require months of work. Once a schedule has been calculated in this manner, the timber planner/analyst is probably not interested in attempting calculation of other possible schedules to identify which will produce the highest first decade harvest; it was hard enough just to identify one viable solution. In other words, though this method may be more accurate than application of earlier simple formulas, it may be no more precise.

Hidden within these calculations are two conflicting assumptions, both dealing with implementation. First, in order for the calculations of ASQ to be valid, it must be assumed that harvest amounts by acres of specific strata as identified in the solution are possible and will occur. Turning that around, the ASQ was calculated based on a harvest pattern by decade by strata. Variation from this pattern will violate the basis of such calculations and in this way invalidate the volume projections for all decades included in calculation of the ASQ.

The second assumption implicit in these calculations relates to the fragmentation of the timber management problem and at least defacto acceptance of a mixed scanning approach to planning and management. This assumption is that the solution represents an ESTIMATE for guiding implementation, but that it is only a guide. Further, that it is the role of the field manager to use this as a guide as she/he also adds the specifics of candidate stands, transportation networks, efficiency of harvest layout, and any other important considerations such as those related to multiple-use production. Because the harvest pattern underlying the ASQ is perceived as an estimate, stands selected for harvest will probably not match the treatment of acres by strata on which the ASQ calculations are based. This, in effect, means that implementation invalidates the calculations that such implementation are based upon. In other words, unless a forest is already arranged as a normal forest with stands concentrated enough for viable/efficient harvests yet dispersed enough to meet other considerations, the two assumptions on which ASQ calculations are based are in conflict. Thereby, the solution so generated is valid only in a very narrow sense.

Enter linear programming (LP). Over the last 20 years, linear programming based analysis systems have been developed to aid estimation of an ASQ and harvest schedule (for example, see documentation in Iverson and Alston 1986). Though there are significant differences between "Timber Ram," "MUSCY," and versions of "FORPLAN," all but perhaps Version 2 of FORPLAN appear to have adopted the same simplifying assumptions of tabular methods. Included in this is the use of timber strata or in more up-to-date terms, homogeneous, non-contiguous analysis areas. (This is not just a feature of analysis systems developed for "timber harvest scheduling" and is found in most linear programming based analysis systems applied to various aspects of forest management.)

What took months to accomplish by tabular methods could be accomplished in a manner of a single "run" of a LP model (Kent 1980 presents a basic primer on use of LP models). Further, within LP models there is the ability to alter the objective function as well as add or delete constraints. This means that the analyst/timber planner can use such models to answer questions such as the maximum theoretical first decade harvest under a non-declining flow constraint or alternatively, an ASQ and schedule that would maximize some measure of economic efficiency. In short, such LP models appeared to provide unparalleled flexibility for an analysis as well as the ability to calculate "optimum" solutions with more precision.

A question at this point is: are solutions so generated optimum? The only response that can be given from an operations research standpoint is: "yes, they are optimum solutions for the problem as defined (ORAs learn early to weasel word such answers)." However, because these models and approved methods for their use (as presented in users guides) did not alter the basic assumptions included in tabular methods as discussed above, solutions from these models can be no more (or less) valid than solutions from tabular methods. Which in turn means that such solutions are optimal but probably not valid in a broader context of providing solutions that can be implemented to resolve forest/timber management problems. (In fact, such solutions may be very misleading.)

A New Problem for Analysts or a New Perspective on the Original Problem

Implementation of solutions from simple equations up through linear programming models has been a problem facing forest managers since such calculations were begun. Though this has been a problem, it did not become a critical problem requiring attention until the last 30 years or so as questions of scarcity and/or inappropriate results from implementation became a concern of society at large. During this time period, controversy has been a constant companion of timber management within the U.S. Forest Service. Though there have been a number of responses such as altering how and which silvicultural practices are applied where, it appears these are treating a symptom of the problem and not the cause of the problem. In their discussion of the genesis of FORPLAN, Iverson and Alston (1986) point out how LP models have evolved in an attempt to address controversies and provide "better" solutions. This has been an extraordinary evolution in analysis procedures and it appears analysis is catching up on the problem. But perhaps we should not be focussing just on the capabilities of analysis systems, but rather on better definition of the problem to be resolved and more appropriate procedures for use of these analysis systems.

The intent of procedures to calculate an ASQ for a forest is to provide information to a forest manager that will assist in meeting society's needs through management actions on that forest. Through time, this intent became clouded as those involved narrowed their focus on more efficient and precise ways to estimate an ASQ. Efficiency can easily be translated into maximization, so the effort to improve ASQ calculations naturally moved toward calculation of a maximum theoretical yield. Solutions are theoretical because of the simplifying assumptions necessary for calculations. Since the creation of the U.S. Forest Service, though, management has focused, at least philosophically, on provision of "multiple-use" mixes of goods and services that can be produced from a Forest in an attempt to meet society's needs for these goods and services. This was explicitly stated in the Multiple Use, Sustained Yield Act of 1960. Further, within the National Forest Management Act of 1976 (NFMA), this appears to have become the focus of Forest Planning and analysis supporting such planning. As such, the problem facing timber analysis has been and is not just to estimate the theoretical maximum timber yield or even to arrange a Forest as a normal forest to produce a maximum sustained yield of timber, but to arrange it to produce a sustained yield of a particular mix of goods and services.

One reading of the NFMA and its implementing regulations (36 CFR 219) illustrates/supports this point by requiring as part of timber analyses supporting Forest Plans analysis that includes:

calculation of an allowable sale quantity and base sale schedule;

detailed accounting of costs, benefits (including multiple-use benefits), and environmental effects of proposed timber harvests included within the allowable sale quantity;

assurances that the optimal silvicultural practices will be applied to specific timber strata as shown in the linear programming solution; and

assurance that solutions can be implemented in a viable manner.

This problem may include calculation of theoretical maximums, but it also appears to require detailed, almost site-specific analysis, in order to estimate costs, environmental effects, and solutions that can be "laid-on-the-ground" almost directly. In other words, this "new" problem statement appears to require that the conflict of assumptions imbedded in earlier analysis procedures regarding implementation be resolved; i.e., that mixed scanning approach relying on analysis using simplified assumptions is no longer reasonable. Further, that the focus of analysis procedures is to generate valid solutions rather than theoretical optimal solutions.

Recognition that there may be a new or different problem to be resolved in timber analysis does not appear to be widely accepted nor does there appear to be agreement on the nature of this new problem (Alston and Iverson 1987). This complicates discussions at forums, such as this conference, where those involved in analysis as well as design of analysis tools discuss the relative merits of various models and analysis techniques. While some are discussing different techniques or enhancements to resolve the former problem more efficiently, others appear to be struggling at understanding how to use the existing tools to solve the more involved problems facing Forest Planning.

Implications and Possible Solutions in Forest Planning

There appear to be three general strategies that can/have been used to resolve this new problem while utilizing analysis tools that were developed to solve the old problem. Briefly, these are:

1. Ignore the problem. Under this strategy, the difference between the two problems is/was probably not recognized by management (some in the public may recognize it, though). In these cases, it is quite common to deal with implementation as a separate problem from planning. In other words, FORPLAN is used to calculate an allowable sale quantity and to accomplish required timber analysis and justification following standard solution procedures (i.e., solve the old problem). This is the province of the forest planners and operations research analysts. Implementation, however, is viewed as a problem separate from development of the Plan.

Implementation of solutions from timber analysis portions of a Forest Plan becomes the responsibility of the timber staff officer and forest silviculturist. Following the traditional approach to implement results of timber harvest scheduling analysis, they use the bottom line volume calculated for the allowable sale quantity as a target to be achieved in timber sales. Timber sales are then planned so that they "fit" the ground in a viable way to produce the desired volume. The harvests by strata identified in the FORPLAN solutions often are not consulted in this on-the-ground layout of sales. Because planning and implementation are separate activities in different parts of an organization, there is probably little if any recognition that there is a problem between the two.

2. Post analysis recognition of the problem. Under this strategy, FORPLAN is used to solve the old problem as in approach 1. However, there is at least a partial recognition that the solution from this analysis supporting a Forest Plan may not be a complete solution to the new problem that was to be resolved in that Forest Plan. Based on this, there is a perceived need to augment the basic analysis supporting a Forest Plan during implementation. This is accomplished through such procedures as Integrated Resource Management or area analysis. These represent attempts to "lay-on-the-ground" a sequenced and integrated set of projects that attempt to achieve both the volumes/acres of treatment and schedules over time by strata called for in analysis. Also such processes address achievement of such items as desired forest conditions, multiple-use production concerns, and environmental consequences on a more site specific manner. In this way, the accounting of costs, benefits, multiple-use production effects and other environmental effects are estimated. In this procedure, mixed scanning is appropriate because the Forest Plan is used as a guide that can be altered based on site specific considerations; i.e., flexibility is provided in this approach for field managers to resolve inherent conflicts caused by assumptions within analysis and amend the Forest Plan when necessary. This approach appears to have a number of advantages over the first approach including the ability to resolve/address the new problem. It is probably the best that can be accomplished given current understanding of problems associated with planning.

3. Pre-analysis recognition of the problem. Under this strategy, at least some of the differences between solutions generated through standard formulations of timber harvest scheduling models and that required to resolve the new problem facing timber analysis in Forest Planning are recognized prior to formulation of an analysis process. The analysis process and formulation of a FORPLAN model are then structured to resolve this new problem. This includes attempting many of the analysis tasks being performed during implementation in approach 2 as part of Forest Planning analysis and entering such information into FORPLAN.

Approach 1 appears a continuation of the way timber analysis and implementation have been accomplished traditionally. It has advantages in terms of simplicity of analysis models and the ability to meet targets assigned as a result of that analysis. Further, because it follows traditional patterns of planning and implementation, there will be little disruption or change from an organizational standpoint. It does not provide a method for addressing/ resolving the new analysis problem and can easily keep forest managers center stage in controversy. Because of this, it may have some significant short-comings; least of which is the validity (or lack) of its "optimal" solutions.

Approach 2 is well documented elsewhere (e.g., Eastern Region, U.S. Forest Service 1985). It appears that the common procedure for formulating a FORPLAN model under this approach is about the same as that in approach 1. That is, timber is modeled much as it would have been under a tabular method for calculation of allowable sale quantities. This includes forestwide homogeneous, non-contiguous analysis areas. Coefficients within FORPLAN represent per acre results of applying a specific prescription (sequence of practices)/timing option to one acre of an analysis area.

Once such a model is constructed, it is used to accomplish timber analysis required for Forest Planning (see 36 CFR 219 and national analysis standards for a discussion of required analysis). Solutions include a listing of the acres to be treated by decade for each strata; and if geographic breakdowns were included within the model, an estimate of acres treated by strata by geographic area. Such solutions are used as analysis support for Forest Plans. However, published Forest Plans normally do not include detail on the amount of treatment expected to occur by geographic area through time. Rather, Forest Plans indicate general management intent by geographic area.

During implementation under approach 2, the Forest is subdivided into geographic areas (sometimes referred to as opportunity areas). The general management direction or directions for that area as published in the Plan are noted and an interdisciplinary team assembled. At this point, attention turns from forestwide considerations and FORPLAN modeling to analysis/identification of projects that could be implemented within this specific area. The focus of this effort is to identify and analyze alternative sets of projects (practices plus standards for application of those practices) that could achieve the general management intent(s) selected for that area in the Forest Plan. During this effort, the FORPLAN solution supporting the Forest Plan may be consulted to identify acres of treatment by strata as a guide. But because strata are normally forestwide in nature, it

may be difficult to track whether projects analyzed for each geographic area will achieve the treatments included in the Plan. Such tracking is further complicated by such common procedures as having different interdisciplinary teams (perhaps one team on each District) working on analysis for subdistrict geographic areas. Also, complete tracking can not occur until all such area analysis is completed. Given that analysis for a single area may require up to 6 months of work and that there may be as many as 80 to 100 areas on a Forest, it could take several years worth of work to complete such analysis.

From an analysis standpoint, the final result (after area analysis is complete) of this staging of analysis can result in near total accounting of costs, benefits, and environmental effects. In this procedure, the general, per acre coefficients in FORPLAN can become much more site-specific through analysis supporting implementation. Through project identification, types, location, and sequencing of timber treatments can be identified. This, in turn, provides information on the overall forest condition that will be created through implementation on a specific area of the forest. This estimate, in turn, can provide a basis for estimating resulting levels of production of those items which have a strong spatial component in their production functions such as wildlife habitat, visual quality, recreation opportunities, impacts on soil and water, transportation networks, and such timber related considerations as integrated insect and disease control and regeneration considerations.

In short, approach 2 appears to utilize FORPLAN and other forestwide analyses to identify general direction for various parts of a Forest. Based on these broad decisions, separate, area-by-area analyses attempt to identify specific projects that both meet the general direction established in the Plan as well as site specific considerations toward achieving some type of desired forest condition, at least in each specific area. In this manner, analysis turns to identification of a possible set of superior solutions and allows "decision-makers" the latitude of selecting among a set of superior solutions. In other words, analysis moves out of a search for a theoretical "optimum" toward the realm of the practical/implementation solutions for problems facing management. This system appears to work fairly well and does appear to provide a mechanism for capturing the multiple-use production inherent in forested ecosystems. Some questions raised by this approach, though, include:

> What is the role of the original FORPLAN solutions?
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> Because tracking between those solutions and results of area analysis is difficult, what was the real value of using FORPLAN? Was it merely to address some policy questions such as the relative merits of harvest prior to culmination of mean annual increment or departures from even flow?
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> If these are the questions that FORPLAN/linear programming was to answer, is there a need for a complex and expensive linear programing model or would something simpler, less costly and less time consuming have been adequate?
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> If site specifics of multiple-use production as well as associated costs such as those for a transportation network are dealt with in subsequent area analysis, how "optimum" are solutions from a FORPLAN model?
>
> If analysis during implementation is done on an area by area method over a fairly long time span, are resulting "solutions" optimal from a forestwide perspective?

With those questions in mind, let us turn our attention on the third approach. A basic assumption underlying this approach is the hypothesis that if it is possible to deal with site-specific considerations for timber analysis through area analysis subsequent to FORPLAN analysis, then it should be possible to deal with these prior to FORPLAN analysis and include them in a FORPLAN model. This sounds simple enough, but requires an alteration in the conceptual basis of constructing a linear programming model for calculation of allowable sale quantities.

Construction of a linear programming model for calculation of an allowable sale quantity often includes:

> forestwide timber strata/analysis areas--timber stands scattered across a forest that are assumed to be homogeneous in terms of response to practices that could be applied to them. This often includes homogeneity of cover type, age class, site productivity, and slope class as well as perhaps such items as soil stability, broad accessibility class, and/or within areas of high sensitivity from a visual or hydrological standpoint.
>
> prescriptions--a set of sequenced practices that could be applied to an analysis area.
>
> costs, effects, and yields--an estimate of these items that will be incurred/produced if/when a prescription is applied to a single acre of the appropriate analysis area. These become coefficients within a linear program.

Construction of such a model, estimates of costs, effects and yields, and analysis using such a model assumes a straight-line, cause and effect relationship between application of a prescription to an analysis area; that is there is a one-to-one relationship assumed between application of a specific practice to an acre of an analysis area and the results estimated as coefficients within the model. Because analysis areas/timber strata are forestwide in nature, this can only be true in a very narrow sense--perhaps only in rough estimates of timber volume to be produced and general economic concerns. Further, unless there is flexibility to alter solutions generated through analysis during implementation, there is a high probability that such results are not implementation and therefore invalid.

In order to improve the probability of solution validity, approach 3 requires a different assumption regarding the relationship between practices and production functions of forest ecosystems. (As will be discussed later, it also requires a

different method for formulating analysis models.) This different assumption is that production of goods and services including timber is a function of how sets of practices applied over time and space alter the condition or state of a forest ecosystem or set of ecosystems within a specific area. In other words, costs, benefits, environmental effects, and multiple use production levels are assumed to be a function of ecosystem states. The role of practices, then, is one of altering the current state. This means that estimation of results of applying a specific practice to a specific area requires an estimation of:

how much of that practice is applied (e.g., how many acres are harvested);

the standards/management requirements/design criteria that will govern application of that practice; and

what other practices are going to be applied prior to, simultaneously, and subsequent to that practice within the same general area (say over a 5,000 to 40,000 acre area) and the standards/design criteria for those practices.

There are a number of ways this third approach can be classified or characterized. Some find it crazy, others find it arrogant, and some dismiss it as "a stupid way to build a model." A more useful way to classify it is that it represents an incremental change within a context of a mixed scanning approach to planning. A mixed scanning approach to planning is represented by approach 2. It could be viewed that all approach 3 does is take the output of approach 2 in terms of alternative mixes of feasible projects that could be applied to an area on a Forest and feeds these into a model for further analysis. The purpose of this further analysis is to identify, based on a look at feasibility and the full set of costs, effects, and production levels, which alternative for each area of the Forest is necessary to efficiently meet forestwide goals and objectives. As such, approach 3 could be considered nothing more (or less) than a final step for completing analysis under approach 2.

One other way that approach 3 can be characterized is as a "systems approach" to planning. Management of a forest is viewed as manipulation of a set of systems (some refer to it as a set of ecosystems). These systems are interacting with each other and with their environment and through this interaction are producing a mix of goods and services. The specific mix of goods and services is defined by the configuration of these systems. In theory, if the mix being produced is not a desired mix in terms of meeting society's needs, then the role of management is to alter the configuration of these systems so that the desired mix of multiple-use goods and services can be produced. (To some, this is little more than a site specific extension of the concept of a normal forest and using that to guide all management activities on a forest.)

Analysis under a systems approach, begins by identifying the current condition of involved systems through such measures as age class distribution, spatial arrangement of habitat components, edge, diversity measures, and/or open road densities of specific, geographic areas on a Forest. A second step, based on problems facing management, is to identify ecosystem states that if achieved on those areas would produce desired mixes of goods and services. A third step, is to identify a mix of practices and associated standards/design criteria for those practices (i.e., a mix of projects) that could be applied to an area to alter its current condition so that it matches one of the desired ecosystem states. Each mix of projects can be considered a "prescription" for that area. Specific consideration of such items as spatial arrangements, age classes, edge, vegetative diversity, desired recreation opportunities, and road densities are included WITHIN these prescriptions. Because there are a multitude of possible ecosystems states that could be achieved in a specific area as well as a multitude of ways to achieve and maintain these states, FORPLAN analysis focuses on sorting through these possibilities to identify not only the mix of ecosystem states that are desired, but specific ways in which this will be accomplished. Results from FORPLAN analyses will thereby be an identification of projects for specific areas on a Forest. In effect, results will be almost identical to results generated through full application of approach 2 including the area analysis done during the Plan implementation phase in approach 2.

(Note/aside--some early proponents of something similar to approach 3 suggested that a first stage of analysis focus on selection of desired forest conditions for various areas of a forest. Once this selection is complete, use this selection as a constraint or set of constraints on a "scheduling" model. This was simplified and classified as a two stage process and rejected by majority of "analysts" in preference to "basic, simultaneous allocation, and scheduling." Though approach 3 may rely on some of the basic concepts of a two stage approach, it is really is much more a modification of a basic simultaneous allocation and scheduling approach.)

Though the final results of approaches 2 and 3 look very much alike, there are significant differences in: potential validity of analysis solutions; when and how "site-specific" analysis is accomplished; how decisions reached on specific areas of a Forest influence and are influenced by forestwide considerations; the time involved in reaching those results; ability to involve the public in a meaningful way prior to completion of a Forest Plan; ability to track solutions from FORPLAN to actual projects on the ground; ability to accomplish cumulative effects analysis in Forest Planning detailed enough for tiering project level environmental analyses; and providing information from FORPLAN that is useful for structuring budget proposals as well as allocation of budgets and "targets" to Ranger Districts. In all of these areas, approach 3 has the potential for significant advantages over approach 2. Before basking in thoughts of how far superior approach 3 is though, a question of some import is whether approach 3 is possible.

A Test of Approach 3

In 1982, the Shoshone National Forest initiated an attempt to implement approach 3. The Regional Office had given the Shoshone a charter to use and test Version 2 FORPLAN as well.

This means that not only was this a test of approach 3, but it was a test of whether approach 3 could be implemented using a currently available analysis system.

The focus of this effort was to create a detailed, nearly site-specific Forest Plan while meeting all Forest Planning analysis requirements. This focus on site specificity was chosen in an attempt to assure solution feasibility as well as deal with multiple-use considerations of timber management activities in what appeared to be a more reasonable manner. This effort required use of three separate, but linked, sets of analyses with each set of analyses requiring a FORPLAN model (Mitchell 1986, Mitchell et al. 1985). The most dramatic differences in these models and normally found are in the third and final model used for analysis, particularly those portions of the model related to timber analysis. The following discussion concentrates on this final model and how it was structured to accomplish required analysis related to timber.

(Version 2 FORPLAN was used for all three models. The following discussion uses terms specific to this analysis system. Those unfamiliar with V2 FORPLAN should refer to V2 FORPLAN User's and/or Programmers Guides or such publications as Mitchell and Kent 1986.)

Before FORPLAN modeling began, the Forest interdisciplinary planning team (ID team) examined problems facing management of the Forest (in Forest Planning jargon, they examined issues, concerns, and opportunities). The focus of this examination was to identify/design specific ecosystem states that if achieved and maintained, would result in sustained yield of a multiple-use mix of goods and services in response to each problem. These ecosystem states were referred to as Shoshone Management Goals [based on the definition of a goal within the Forest Planning regulations (36 CFR 219.3)]. Each goal for timbered ecosystems contained such information as a desired age class distribution/structural stages, desired size of canopy breaks (e.g., 5 to 10 acre clear cut patches for water flow enhancement or 26.5 acre openings for elk habitat improvement), total road density, open road density, and visual quality objectives. The level of specificity included was dictated by the level of specificity necessary for each specialist to estimate multiple-use production levels that would result from achievement of such ecosystem states.

Identification/design of Shoshone Management Goals was done for two separate reasons from an analysis standpoint; both dealing with standards/management requirements/design criteria. First, within analysis requirements for Forest Planning, there is a requirement to analyze "opportunity costs" and relative cost efficiency of standards that are felt necessary for production of goods and services other than timber. This analysis requirement appears to stem from use of "constraints" within a linear programming model which are justified as necessary in order to meet "minimum management requirements" or other desired levels of multiple-use production. In more conventional model formulations, such "constraints" are common as a means for representing management standards. Identifying opportunity costs of such constraints is relatively easy by making "paired" runs of the linear program model--one with a constraint(s) and one without--and then comparing results.

In order to apply approach 3, it is necessary to include standards within each prescription. Such standards are necessary because of the assumption that production is a function of forest conditions. In other words, in order to estimate costs, benefits, multiple-use production levels, and environmental effects, it is necessary to identify what forest conditions will result from application of practices to specific areas on the Forest. This means that a linear program model used in approach 3 does not utilize constraints to represent standards, rather they are included within prescriptions so that estimates of effects and production levels can be made. If standards are included within prescriptions rather than as constraints, analysis of opportunity costs using "paired" runs is not possible. What is possible is to build a model which includes alternative prescriptions, each with a different set of standards. Using such a model, it is possible to analyze differences in production levels and economic measures generated by different sets of standards. In this way, it is possible to identify the most cost efficient set of standards. It also is possible to analyze "opportunity costs" between these and "unconstrained" prescriptions.

Unconstrained in approach 3 takes on a different meaning than in more conventional modeling. Part of this difference relates to how analysis models are formulated as discussed. Another part of the differences relates to the basic assumptions underling estimates of production; i.e., in order to make such estimates, a "systems approach" requires identification of the anticipated forest condition that would result from implementation of practices included in a prescription, which in turn requires identification of standards that will be used to guide implementation of practices. Thus "unconstrained" really means identification of different sets of less restrictive standards than that necessary for meeting multiple-use management requirements; e.g., allowing harvest blocks to have straight edges and cover areas as large as several hundred acres at a time.

This highlights a basic difference between approach 3, other approaches, and standard modeling as done using such tools as Timber Ram and MUSYC. All but approach 3 assume that it is possible to capture multiple-use and environmental effects just by knowing that a practice is going to be applied to a single acre of a forestwide timber strata regardless of where that acre is on the forest, standards that will guide application of that practice, and what practices are being applied to adjoining areas. That is what is included as coefficients in a linear programming model. In approach 2, this assumption is altered slightly to become: it is possible to capture enough of these effects within a linear programming model to make a reasoned decision on an alternative, but final accounting of these will not occur until "area analysis" is done. In area analysis, it will be possible to examine what practices are going to be applied and their spatial and temporal relationships on a specific area.

The assumption underling approach 3 is that it is not possible to estimate multiple-use and environmental effects just by knowing that a practice will be applied to a single acre of land

at a specific point in time. This point appears to be a major conceptual difference among many who have been involved with National Forest Planning. (This difference in basic assumptions is rarely discussed or acknowledged. Because of a lack of recognition of this difference, discussions between people with different perceptions focus on "modeling" techniques and why a particular enhancement may be needed. These discussions have often been heated and no conclusions reached because of a lack of understanding and discussion of differences in basic assumptions.)

A second reason for identifying desired forest conditions (Goals) prior to analysis is to provide direction for construction of prescriptions. Treatment of timber stands including harvest of that timber can and does have effects on production of other goods and services as well as environmental effects. Before such harvest or other treatment is done in the field, alternative ways of doing this are normally investigated in an environmental analysis. At this stage, an interdisciplinary team is normally involved in design of application of treatments and often include consideration of "optimizing" multiple-use production effects of these treatments. In approach 3, such ID team deliberations and design considerations are to be explicitly included within prescriptions. In order to do this, it is necessary for an ID team to identify how such treatments and harvests could be applied to "optimize" production of one or more multiple-use mixes of goods and services. This is the type of design included in development of Goals which results in identification of alternative sets of standards for application of practices. This in turn, provides information necessary for estimating costs, benefits, and effects of prescriptions to be included within a linear programming model.

Formulating a linear programming model to implement approach 3 requires dealing with two opposing types of considerations. On one hand, there is a need for "site specificity" in analysis, including specification of both spatial and temporal sequence of activities to be implemented within a geographic area. On the other hand, analysis should include a "wide range" of timing choices for activities in order to deal with such issues as non-declining timber flows and investigation of maximum production possibilities through time. Version 2 (V2) FORPLAN is a powerful and flexible analysis system which provides many alternative methods for modeling about anything of interest, but particularly timber. Most of these methods were investigated by those involved with planning on the Shoshone National Forest as ways to achieve the specificity necessary for approach 3 as well as generation of a wide range of timing choices necessary to accomplish required analysis. Some of these options provided either the necessary specificity or the flexibility, but not both. Therefore, it was necessary to build a "composite" model which combined available options, as well as utilized a slightly different definition of "prescriptions" than that used in conventional modeling. [Discussion of this difficulty and other attempts to resolve it is presented by Iverson and Alston (1986) in terms of "enhancements" in both versions of FORPLAN.]

In order to deal with these two considerations, two ways of representing analysis area information were combined. This included linking heterogeneous, contiguous analysis areas with "allocation scheduling zones" containing homogeneous, noncontiguous analysis areas. Prescriptions for these combined analysis areas could also be considered "compound" prescriptions. Such prescriptions were combinations of "Directly Entered" prescriptions and "Themed" prescriptions and again were linked to form a single set of choices within the model. (Hopefully, that set of sentences can be translated into something approximating common parlance in an understandable manner.)

In order to define a set of analysis areas, the Forest was subdivided into 109 geographic areas. Each of these are large enough to deal in a reasonable way with transportation networks (including trails), watershed considerations, habitat or migration routes for wildlife, recreation and visual considerations, and diversity. These areas were then represented in the model in two different ways. First, all of the land within the boundary of a geographic area, except that which had been defined as tentatively suited timber land, was modeled as a contiguous, heterogeneous analysis area. (Some of these analysis areas were entirely within classified wilderness areas, so all land within the boundary was included in such analysis areas.) For each of these contiguous, heterogeneous analysis areas that had tentatively suited timber land within their boundary, an allocation schedule zone was created. Outside boundaries for each allocation schedule zone matched the boundary of its associated geographic analysis area.

Tentatively suited timber land within the boundary of an allocation schedule zone were then represented as homogeneous, noncontiguous analysis areas. Even though these analysis areas were confined to specific geographic areas on the Forest (i.e., they were not forestwide strata), the definition of these are the same or similar to timber strata used in conventional models; i.e., each such analysis area was homogeneous in terms of cover type, age class, possible cover types, productivity, and response to silvicultural practices. In effect, an allocation schedule zone was nothing more than a collection or set of all timber strata within its boundary with each strata retaining its own identity. This grouping into zones was done for two reasons. First, to provide a mechanism for coordinating activities within a specific area through use of another V2 FORPLAN feature referred to as coordinated allocation and scheduling choices. Secondly, to provide capability for using FORPLAN reports to identify the specific activities/prescriptions selected for each geographic area on the Forest.

Prescriptions within the FORPLAN model represented a mix of practices and associated standards. Identification of practices and standards to be included within prescriptions was based on descriptions of desired forest conditions/ecosystem states. For example, a possible desired state for timbered areas along a migration route for elk is to have a portion of that area in 26.5 acre openings that are surrounded by cover. Given this, at least one of the prescriptions included within FORPLAN for

such areas included appropriate harvest practices that will be implemented under a set of standards that limit size of openings to 26.5 acres and dispersion of harvest blocks over time and space in order to provide cover surrounding these openings. Standards for all practices including such things as road construction, transportation network management, range management, trails, and wildlife habitat improvements as needed to achieve designed (not necessarily selected) ecosystem states were also included within prescriptions.

In this attempt to implement approach 3, the word "prescription" takes on a meaning different than that normally used in conventional modeling, particularly for geographic areas containing tentatively suited timber land. In conventional modeling a prescription is a set of practices that can be applied to a single acre of an analysis area. Coefficients within such models represent only those effects which can be estimated on a per acre basis. In the Shoshone's attempt at approach 3, a prescription is a coordinated set of projects (practices and standards) to be applied to a specific area in a specific sequence. Coefficients within the model represent the estimated combined effects of applying those projects to that area, including effects that have strong spatial components within their production functions (e.g., useable wildlife habitat). In this way, the ID team could model solutions to site-specific management problems on a geographic area by geographic area basis. In order to do this while still providing a wide range of timing choices (particularly for timber), "prescriptions" for areas containing tentatively suited timber land had three components. In other words, it is not possible to examine a single portion of the input data to identify what is included within a single prescription.

Prescriptions for those areas which did not contain tentatively suited timber land were "directly entered" prescriptions. Use of directly entered prescriptions is a unique feature of V2 FORPLAN and allows specification of the amount of each practice, cost, effect, output, and benefit anticipated through time for a specific prescription for a specific analysis area. In effect, a directly entered prescription is little more than a column in the resulting linear program matrix. For these areas, the ID team working with field personnel, identified various sets of projects which could be implemented within these areas to address both site-specific and forestwide management problems. Each set of projects covered a span of at least 100 years as did estimates of goods, services and environmental effects. For these analysis areas, prescriptions were "straight-up" application of the direct entry option in V2 FORPLAN.

For those geographic areas which contained tentatively suited timberland, prescriptions were disaggregated into three linked parts. The first part was a directly entered prescription. This represented a coordinated and sequenced set of projects (practices and standards) necessary to alter the current condition of all but the tentatively suited timberland within a geographic area toward achievement of a specific mix of ecosystem states in response to both site-specific and forestwide management problems. These directly entered prescriptions were similar to those developed for areas that did not have tentatively suited timber land. As such, these prescriptions included estimates of the costs, output levels, benefits, and effects that would result from implementation of those projects. This included such items as the amount and timing of arterial and collector roads necessary to support the overall intent of a prescription. Estimates of effects and/or output levels included within these prescriptions were based on a specific mix of projects including their spatial and temporal relationships.

The second part of a prescription for those geographic areas containing tentatively suited timber was represented as a Coordinated Allocation and Scheduling Choice for the appropriate Allocation Scheduling Zone. As stated earlier, all of the timber strata within a geographic area were collected as a set; i.e., within an allocation scheduling zone. One of the options available in V2 FORPLAN when such sets are used, is the ability to identify a set of management options available to strata within that set, as well as do such things as identify when access to various portions of each strata will be available. This is referred to as a Coordinated Allocation and Scheduling Choice (CAC). Using this feature, it is possible to develop a CAC that is coordinated with the directly entered prescription for a geographic area in terms of overall management strategy, as well as such considerations as specific schedules for construction of collector and arterial roads. It is also possible to include estimates of effects, costs, benefits, and output levels that could be produced given this CAC. In order to link a particular coordinated allocation and scheduling choice for a specific allocation scheduling zone with the appropriate directly entered prescription for a geographic area, it was necessary to develop a transfer row through the use of a specific output and set of constraints. This had the effect of making a specific CAC and directly entered prescription appear to be a single option within the resulting FORPLAN model. (As a unanticipated side benefit, this had the result of nearly transforming a linear programming model into an integer programming model.)

What all of that means is that it was possible to link a coordinated set of non-timber projects with a set of compatible timber projects for a specific area on the Forest.

Within a CAC, it is possible to identify the types of prescriptions available for timber strata within the appropriate allocation and scheduling zone. In this way, it was possible to identify which types of timber projects (practices and standards) would be appropriate and compatible with the intent of a particular CAC. These were identified as part of the definition of a CAC. Within sideboards set by such selections of types of timber projects within a CAC, there are a number of possible times when various types of silvicultural treatments could occur on each strata within a geographic area. Which timing choice for how many acres of which strata is most appropriate for producing a forestwide level of timber through time as well as having desired simultaneous multiple-use effects is a major question to be addressed in Forest Planning. In V2 FORPLAN, an option referred to as "theming" can be employed to efficiently generate a full (or at least reasonably full) set of management strategies and timing options for each strata. This option was used here.

Prescriptions that were themed in this effort, however, differed from "timber harvest prescriptions" used in more conventional FORPLAN model formulations. In more conventional models, timber harvest prescriptions include specific practices that could be applied to a single acre within a timber strata and include costs, benefits, and associated multiple-use production effects that can be estimated on an acre-by-acre basis. Unless otherwise constrained, solutions from such formulations can include harvesting an entire strata within a specific time. This may not yield a desired ecosystem state unless all acres of each timber strata are already well arranged spatially and in terms of age class distribution. (If all acres were already well arranged in these terms, solution of the "problem" of estimating an allowable sale quantity and base sale schedule would be a trivial problem.) Given that the approach on the Shoshone was to be a systems approach, a different formulation appeared to be necessary.

This different formulation involved attempting to include within a themed prescription for a timber strata a specific set of standards on such things as: size of openings to be created; amount of the strata that could be harvested at any single time; design standards for harvest block layout; local road densities; management of these roads (e.g., open for public use following harvest operations or not); and other requirements necessary for achieving a desired ecosystem state and its associated multiple-use mix of goods and services. In this manner, specialists on the ID team had some basis for estimating production levels of goods and services which have a strong spatial component within their production functions; e.g., usable wildlife habitat and/or recreation opportunities/use. These estimates as well as estimates of costs of all relevant practices and necessary actions to meet standards included within a prescription were included as part of that prescription for a particular strata. This meant that if the solution assigned all acres of a particular strata to a single timing choice within a "themed prescription," only a specified portion of that strata would be harvested at any one time and harvest of the remaining portions would occur at specific intervals. In this way, it was hoped that harvest scheduling of strata acres from the FORPLAN solution could be placed on the ground in a manner consistent with achieving a specific ecosystem state and in a manner coordinated and consistent with management of surrounding/surrounded non-timbered areas. (A discussion of specifics of how this was accomplished within FORPLAN is beyond the scope of this paper, but can be acquired by contacting the Shoshone National Forest.)

Within the final model used to accomplish analysis supporting the Shoshone Forest Plan, then, is:

a set of analysis areas representing specific geographic areas on the Forest. Acreage of these analysis areas was the total acreage within the area boundary minus acres of tentatively suited timberland.

timber strata representing stands which are homogeneous in terms of cover type, condition of cover type, possible cover types, age class, and response to silvicultural practices as well as all within the same geographic area.

allocation schedule zones with each zone comprised of all tentatively suited timber strata within a specific geographic area.

directly entered prescriptions for the geographic analysis areas that represent a coordinated set of projects (practices and standards) designed to alter the current condition of an area to that described by a specific ecosystem state or set of ecosystem states.

coordinated allocation choices for the allocation schedule zones that specified a set of prescriptions available for timber strata included within a specific zone. Each such choice was linked to the appropriate directly entered prescription for the geographic area that matched the allocation schedule zone boundary.

themed prescriptions for timber strata that included practices and standards necessary for achieving and maintaining a desired ecosystem state through time.

Analysis Using this Model

From this model description, a number of implications/conclusions can be drawn regarding assumptions included in analysis and the type of analysis possible. In more standard timber harvest models, it is assumed that all significant production effects can be captured on a "per acre" basis; that is most of the significant production effects can be estimated if we know what practice is going to be applied to one acre of a particular timber strata. This was an assumption carried over as a simplifying assumption so that tabular methods would be possible. Further, this appears a reasonable assumption if one is attempting to estimate the maximum biological allowable sale quantity and sustained yield level possible. Again, that was one of the questions/part of the problem for which analysis tools such as Timber Ram, MUSYC, and the at least major portions of V1 FORPLAN were developed. If this is the question or at least one of the major questions, then other simplifying assumptions/modeling techniques may be appropriate such as use of forest-wide, non-contiguous, homogeneous analysis areas.

Approach 3, as discussed above, identifies the problem to be resolved differently. That is, calculation of the maximum feasible allowable sale quantity and estimation of the entire range of multiple-use effects that would result from this. Under this approach, it is assumed that simultaneous production of multiple-use goods and services (including timber) occurs on a forest and is a function not only of the practices applied to each acre, but the standards/management requirements guiding such application and how those practices are applied over time and space. In short, it is assumed that significant production effects are related to resulting forest conditions/ecosystem states rather

than to practices. This approach requires becoming more site specific in terms of analysis areas than in other approaches.

The FORPLAN model formulation described above was an attempt to solve this second problem--that of a "feasible" allowable sale quantity along with associated multiple-use production effects. Because a variety of desired ecosystem states were included in alternative "prescriptions" as well as a full range of timing options for implementation of practices (including silvicultural practices), it was possible to use this final model to investigate a full range of production potentials for all goods and services (benchmark analysis), as well as a full range of Forest Plan alternatives for which there was reasonable assurance of implementability of FORPLAN solutions. Further, it was possible to meet most analysis requirements using this final model.

Analysis requirements that could not be readily met with this final FORPLAN model include:

calculation of MAXIMUM BIOLOGICAL: allowable sale quantity, base sale schedule, and sustained yield level; and

calculation of "opportunity costs" of meeting dispersion standards.

Because standards on the amount of any single timber strata that could be harvested at any time were included within "prescriptions" in the final model, there was concern that results from the final model would not be deemed sufficient for meeting these analysis requirements. This was one reason for use of more than one model for analysis under this approach. One of the other FORPLAN models used in analysis was a "straight-up" timber harvest scheduling model. This model only included tentatively suited timber lands modeled as forestwide timber strata (homogeneous, noncontiguous analysis areas). Prescriptions included in this model were also "standard" in terms of representing unconstrained application of silvicultural practices that could be applied to each strata. Using this model, alone, it was possible to meet the first set of analysis requirements listed using standard analysis procedures. It was also possible to investigate other analysis questions such as effects or "opportunity" costs (in terms of timber volume) of nondeclining flow considerations and harvest prior to culmination of mean annual increment. Further, by comparing results of this model with results from the final FORPLAN model for similar problem formulations, it was possible to investigate "opportunity costs" of standards included in the final model, including dispersion standards. Timber strata definitions, with the exception of spatial location, were identical between these two models as were the basic timber yield files. This not only provided reasonable assurance that results from the two models were comparable; but made construction of the timber model almost a trivial exercise because all necessary data had already been developed for the final model. (A description of the full set of analyses accomplished using these models as well as results of such analyses can be found in Appendix B of the Environmental Impact Statement supporting the Shoshone Forest Plan.)

Results and Implementation

Using this analysis procedure and the final FORPLAN model resulted in solutions which identified a set of integrated and sequenced (at least by decade) projects for each of the 109 geographic areas. This included identification of the acres by timber strata within each geographic area to be treated each decade and the standards and ecosystem state such treatments should be designed to meet. Such results are basically the same information at approximately the same level of detail as that which would result through full implementation of approach 2. Time and analysis costs for this approach for producing a Forest Plan are probably at the high side of average for Forests implementing approaches 1 or 2. However, in approaches 1 and 2, there is a considerable amount of additional work to be done during implementation in terms of identifying sets of projects necessary to implement Forest Plan direction. Under approach 3, all that remains is "ground-truthing" selected projects. In this way, the ability to move directly into implementation is both simpler and greatly reduced in time, effort, and costs under approach 3.

Once analysis had been completed, reports from FORPLAN were generated on a geographic area by geographic area basis. This provided information for each area that identified:

the full set of practices to be implemented within the first 10 years on that area (including acres of each timber strata within that area to be treated by specific silvicultural practices);

standards/design criteria for those practices including information on the ecosystem states desired within that area; and

anticipated multiple-use production effects and other anticipated environmental effects of applying those practices under those standards.

This information for the first decade was translated into something approximating common usage English and published on an area by area basis within the Forest Plan. In this way, the public as well as those on the Forest involved in implementation, could easily identify what projects were planned for each area on the Forest. (This appears to have facilitated public review of the Proposed Plan as well as their ability to offer useful information for possible changes between the proposed and final Plan.)

Implementation is a relatively straightforward task. This involves identifying a reasonable sequence for projects selected for each geographic area on a year by year basis (e.g., build the collector road before preparing a timber sale accessed by that road). Then for projects that are to occur early within the first decade, "ground truth" the feasibility of those projects and begin project level, site-specific environmental analysis. And finally, once this environmental analysis is completed for a project, implement that project and monitor results.

Because results from FORPLAN were "site specific," tracking between the solution from FORPLAN and actual projects to

be implemented is almost a trivial problem. However, there remains a measure of discretion and judgment provided for those involved in implementation while keeping implementation consistent with results of FORPLAN analysis. Identifying timber stands to be treated within the first decade is a good example of this. Because standards were included within FORPLAN on the maximum amount of each strata that could be harvested within a geographic area at any one time, there is almost always at least three times as many acres of that strata within a geographic area than that scheduled for treatment in any decade (minor exceptions included application of selection harvest systems and the final stage of shelterwood harvests on stands where such systems were initiated prior to the Forest planning effort). This means that District personnel have an opportunity to map and examine in the field all stands within a strata scheduled for treatment during the first decade within a geographic area. Because there are at least 3 times as many acres of such strata than the number of acres selected for treatment, choices must be made as to which of these candidate stands should be treated (i.e., which stands are going to comprise a timber sale). Criteria for such selections include such items as which stands "need" treatment the most from a silvicultural standpoint, ability to achieve design criteria necessary to achieve the desired ecosystem state (including dispersion standards), necessary construction and location of local (timber hauling) roads, and economic considerations. This is best carried out by an interdisciplinary team so that a viable timber sale which meets all design requirements can be implemented. The same is true for such projects as non-structural range and wildlife improvements (e.g., treating sage brush or willow), structural range improvements (e.g., spring developments), and/or recreation developments (e.g., construction of trailheads or trails). In all of these instances, though the projects are identified in the FORPLAN solution for a geographic area, there is a necessity for field inspection and professional judgment on the exact location and methods to be used. Guidance for this level of project design is provided by management requirements (standards) included in the Plan for each practice, as well as the description and design criteria included for each ecosystem state (Shoshone Management Goal) selected for each area of the Forest. In this way, latitude is provided for use of professional judgment while providing consistency between implementation and all assumptions supporting FORPLAN analysis as well as results of that analysis.

There are at least two other features of this analysis procedure and resulting Forest Plan that appear to simplify implementation. The first is the ability to deal with questions regarding cumulative effects. Each project identified for a geographic area was selected to alter the current state of an area and achieve a specific ecosystem state. Because these states and analysis were designed to take spatial and temporal factors into consideration, it was possible to estimate the overall effects of all projects selected for a specific geographic area within analysis supporting the Forest Plan. In effect, this accomplishes a cumulative effects analysis. Geographic areas included in analysis were large enough (5,000 acres to 40,000 acres) to capture those effects which would be significant for wildlife, visuals, recreation, vegetative diversity, and hydrological considerations. Therefore, as long as projects are designed to meet management requirements included within the Forest Plan (including achievement of specific ecosystem states), then the cumulative effects analysis supporting the EIS for the Forest Plan can be used through "tiering" of environmental documents to support project environmental analyses.

A second feature that aids implementation is the ability to use FORPLAN reports to provide information for budget proposals and disaggregation of budgets (and targets) to Districts. Boundaries for geographic areas within FORPLAN did not cross District boundaries. Using an option from V2 FORPLAN referred to as flat files, it is possible to use FORPLAN to create District by District information systems listing the amount and cost of each practice, as well as estimates of production levels for each good or service to be implemented during the first decade (or any other decade for that matter). Database management/report writer software on the Forest can then be used to display this information and these displays can be used as a basis for developing "project files" that include costs by management code for each project to be implemented. Such project files can then be used to build budget proposals as well as disaggregate budgets and targets to Districts.

Conclusion

The focus of timber planning analysis, until recently, was to estimate acres to be treated and/or volumes that could be produced in order to move toward achievement of a "normal" forest condition in a systematic and regular way (e.g., nondeclining flow of timber production). Linear programming methods for solution of this problem were developed using the same simplifying assumptions underlying tabular methods. These linear programming methods provided analysis tools far more flexible than tabular methods and capable of addressing "optimal" solutions. Because "problem" formulation and simplifying assumptions built into these models did not change from those assumed for tabular methods, solutions generated using these models could not be anything more than solutions generated using tabular methods; that is an estimate of an allowable sale quantity based on biological/silvicultural considerations that may be feasible in terms of on-the-ground considerations.

This type of solution is appropriate for the problem as defined, particularly if one accepts as appropriate a mixed scanning approach to planning and implementation. That is, that solutions so generated are estimates of volume and that such estimates can be revised during implementation. But, solutions are not normally viewed as estimates, rather they are often translated into "hard targets" and used as measures of performance for field managers. This can result in a conflict between these solutions generated using simplifying assumptions and what appears viable on the ground.

Further complicating this situation is the fact that the "problem" to be resolved in timber analysis has changed. Timber analysis (or planning) is now part of Forest Planning with attendant expectations of feasibility of solutions; estimation of all relevant costs, benefits, and multiple-use production effects of applying silvicultural treatments; and close ties to actual implementation of projects.

Three methods for addressing this new problem were discussed. The first of the three "approaches" above really never addresses solution of this new problem and can be dismissed. The second of these methods can be apparently classified as a full mixed scanning approach. In this approach, solutions from FORPLAN are combined with decisions on management emphasis for specific areas based on non-FORPLAN analysis at the Forest level during Forest Plan development. Once a Forest Plan is finalized, these two are combined in a series of post-plan analyses commonly referred to as area analysis. Focus of this analysis is to identify integrated sets of projects that will achieve the overall management emphasis of a subforest area while producing volumes of timber which approximate the allowable sale quantity. Because of the time involved in these post analyses, discrepancies between that called for in the Plan and that actually produced may not appear until near the regularly scheduled time for Forest Plan revisions. Taken as a single, though staged, analysis procedure, this approach does appear to adequately address solution of the new problem facing timber analysis/planning. Full application of this approach, however, may require significant time (a decade) and questions can be raised regarding the adequacy of analysis supporting the published Plan.

The third approach attempts to capture all analyses included within the second approach, but accomplishes this prior to publishing the Forest Plan. This can be viewed as an incremental step in applying a mixed scanning approach because it includes all/most analyses involved in the second approach. A more appropriate classification of this approach, though, is an applied "systems approach" to planning and management. By altering analysis assumptions, as well as problem formulation, it appears possible to implement this approach using V2 FORPLAN. This approach appears to completely resolve the new problem facing timber analysis. Costs and time involved are significantly less than approach 2. And the ability to move directly into implementation in a traceable and supportable manner are significantly improved. Further, other benefits of this approach may include an enhanced ability to involve the public, tiering of environmental analyses (e.g., cumulative effects), and providing an information base to support budget proposals as well as disaggregation of budgets.

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The Next Generation of Planning Analysis in the Forest Service

Brad Gilbert[1]

Abstract.--The Forest Service has received a substantial amount of criticism on the analysis procedures used during the first round of planning. As a consequence there has been a search for simpler tools for use in analysis during plan implementation. Simultaneously a handful of forests are building new FORPLAN models as part of their forest planning analysis. These facts lead to the need for the Agency to have a plan for improving the analysis done by forests. An overall framework is proposed in this paper for accommodating the short term needs of the Agency while allowing the flexibility to adapt to new planning analysis tools as they become available.

The title of this paper may lead you to believe that there will be an enlightened discussion of some new high tech analysis procedure for the Forest Service. Actually a different tack is taken. I intend to examine some immediate needs which face the Forest Service and, in so doing, build a case which argues the next generation of analysis is upon us now. The format of the paper will be to discuss some problems facing us, examine criteria for resolving the problems, propose a framework for solving the short term problems, and set the stage for future analysis in the Forest Service. The basic premise behind this paper is while some parts of the organization are examining the big picture, work continues. If we do not improve our analysis procedures now, we will be vulnerable to appeal and litigation over the same issues upon which we have already been taken to task.

There are three related facts which present problems to the agency. First, we have received substantial criticism both from inside and outside the agency on the analysis procedures and tools which were used during the first round of forest planning. This is, in no small part, due to the fact that in the rush to complete forest plans the analysis which was done was not understood, interpreted, or refined to the extent possible. Consequently, the analysis has not been used as it might have been; and some have questioned its usefulness. The second fact is in part a response to these concerns. As part of plan implementation, there is a search for simpler more user friendly analysis tools. Finally, we have several forests building new FORPLAN (Johnson et al. 1986) models to respond to concerns over earlier work, to address new information or issues, or as part of the next round of planning. It is imperative that the lessons learned from past analysis be made available to those undertaking the next generation of analysis.

It should be noted that this paper does not address the quality of information used in analysis. Even though this is an extremely important issue, it goes beyond the scope of this paper. The framework presented below emphasizes the significance of quality information on the decision process.

In the next section, I will explain in greater detail why these facts are problematic and develop some criteria which will help to resolve the problems. This paper assumes the reader has some familiarity with the Forest Service planning process and FORPLAN. If not, consult FORPLAN: An Evaluation of a Forest Planning Tool (Hoekstra et al. 1986) and the National Forest Management Act (NFMA) Regulations (36 CFR part 219). It is important to give credit to the many people who have been working to integrate and simplify the information flows and analysis in forestry. This paper is a compendium of ideas from many sources interpreted in the Forest Service context and in the current hardware/software milieu. A partial list of the sources of many of these ideas follows: Northern Arizona University's Terrestrial Ecosystem Analysis and Modeling System (Dykstra et al. 1987), Forest Service Region 1 (Merzenich 1986, Tanke 1986, Timko 1986), Region 5 (Barber 1986), Chattahoochee-Oconee N.F. (Hilliard 1986), Integrated Pest Impact Assessment System (IPIAS - White et al. 1988), Kirkman et al. (no date), Nicolet N.F. (Loh 1987), Davis and

[1]*Planning Specialist, Land Management Planning Systems Section, USDA Forest Service, 3825 E. Mulberry, Fort Collins, CO 80524.*

Reisinger (1987), Weisz and Carder (1975) and Long Range Direction for Timber Management Information Systems (Sonnen 1984).

EXPLANATION OF THE PROBLEMS

Criticisms of FORPLAN

Criticisms of forest plan analysis have spanned the spectrum from "too much" to "not enough." The "too much" criticisms generally relate to too big, too complex, too costly, too time consuming, etc. (Bare and Field 1986). On the other hand, some critics say there are not enough choices, not enough alternatives, not enough spatial detail, etc. (These sorts of criticisms are embodied in many appeals.) Forest Service analysts have echoed similar concerns during the development of forest plans. However, there has been no consensus on the appropriate level of detail. Upon closer examination, many of the criticisms from both the technical and non-technical critics stem from poor explanations of the assumptions and decisions embodied in the model. On the results side, failure to explain model interactions and implications account for many of the criticisms.

Beyond concerns about how analysis was done, some critics are asking why the Agency chose FORPLAN as its primary analysis tool (Bare and Field 1986, Johnson 1986). Many alternatives have been suggested ranging from no computer analysis to even more complex systems embodying risk and uncertainty. However, none of the alternatives have been given the "acid test" in the forest planning context.

Certainly there is an element of truth in some of the criticisms leveled at forest plan analysis. However, some of the criticisms call into question the planning process as outlined in the regulations. Such questions will be examined when the regulations are reviewed next year. In the meantime it is necessary to assume the regulations will remain about the same and to proceed.

Simple Implementation Approach

Frustrations with FORPLAN analysis within the Agency have been a major force influencing the attitudes toward analysis in plan implementation. In a sense, there has been a backlash against seemingly complex analyses. On the other hand, the job of plan implementation is, in many cases, as complex as the job in forest planning, if not more complex. The process used to implement the plans is the basic National Environmental Policy Act (NEPA) process which makes it similar to the forest planning process. However, in the forest planning process, spatial considerations were at a larger and simpler scale. When it comes to laying out projects on the ground which comply with the plan standards and guidelines and do not foreclose future options or our ability to meet targets, the problem becomes fairly complex. In the face of these difficulties and the close scrutiny given many of our projects, many implementors are choosing simpler tools (in some cases no tools are used). Some of these simpler tools are surprising in their capabilities. However, their use leads to several concerns. First, although integration can occur at several points in the process, there is less certainty that it will occur if not included in the analysis step. Moreover, it becomes more difficult to estimate and document all of the environmental consequences of proposed actions. Approaching implementation without integrated analysis fosters a return to functionalism. In many instances the discipline with the tools is in the driver's seat with other specialists relegated to a reactionary role.

Beyond this is the problem of painting oneself into a corner. While this is not a universal problem, some forests will have difficulty finding a way to lay projects on the ground to meet the outputs specified in the forest plan. It can be demonstrated that a casual approach in the short run will lead to an inability to obtain necessary outputs within the plan standards and guidelines in subsequent time periods. Some tools are available to help avoid this problem. Of these tools, some have been shown to provide more economically attractive solutions (Jones et al. 1986). This fact is particularly important in view of the below cost sale issue facing many forests.

It should be noted while many of the tools on micro and mini computers are excellent, their alleged simplicity is open to question. They may be easy to run once the data set is built, but collecting the necessary information and putting it into the model is not always a trivial task. Moreover, many of the tools, while seemingly simple for small prototype problems, quickly become an input nightmare when attempting to do real problems, e.g., spreadsheets. Finally, many of these tools lack error checking which may lead to erroneous results.

When thinking about the role of analysis in the Forest Service, it is important to examine the audience which will be using the tools. During the first round of planning, we had a substantial number of trained analysts. Many of them have moved outside the Agency or into mainstream jobs within the Agency. During plan implementation, the analysis job is being undertaken by other resource specialists. Another trend is for employees on districts to do more analysis. Hence, the market place for analysis tools has changed. Users are less sophisticated and, after having experienced "user friendly" systems, will not tolerate old software technology.

The Next Generation of Analysis

One would think, following all of the work done to produce the 15-year plans, there would be a lull in forest planning analysis. This would provide an opportunity to evaluate what was done before and how things can be improved. Obviously, we will attempt to do this; but, as frequently occurs, there is an immediate need. The Tongass National Forest is revising their 1979 plan, and they are building a new model. The Bridger-

Teton and the Arapaho-Roosevelt National Forests are also building new models to respond to criticisms of their earlier analysis. Also, a number of forests are either in the process or considering building new models to update their analysis and to make a better tie to plan implementation. What this means to me is that the next generation of analysis has begun. To avoid making the same mistakes that were made in the first round of planning, we need to help forests improve their analysis. The remainder of the paper will lay out criteria for improving analysis in the Forest Service and provide a recommended framework for analysis in the Agency.

PROBLEM RESOLUTION CRITERIA

Solving these problems necessitates the development of a set of criteria which will determine when and if the problem is resolved. Admittedly the criteria presented below are general, but they can be refined as work progresses. Before launching into the criteria, however, it is necessary to build a case for the use of FORPLAN in the next generation of planning analysis. Once this is taken care of the important issues related to solving the defined problems can be addressed.

The Case for Using FORPLAN in Forest Planning

In NFMA Congress essentially adopted a rational comprehensive approach to planning (Teeguarden 1987). Teeguarden (1987) further states:

> "NFMA and the implementing regulations require some form of mathematical modeling of the land management system to insure program feasibility, incorporate technical relationships, reflect resource availability, insure decisions are consistent with policy objectives and constraints, and for conducting tradeoff analysis."

Later in the same paper he notes:

> "Also, the model must have a capability for handling analyzing timber management programs including temporal harvest scheduling, identification of suitable timber lands, rotation policy and selection of appropriate silvicultural systems."

Teeguarden concludes FORPLAN is very strong in meeting 19 forest level analysis requirements that he infers from the NFMA regulations.

Rodger Sedjo and John Sessions summarized the symposium, FORPLAN: An Evaluation of a Forest Planning Tool. Sedjo (1987) concluded:

> "While FORPLAN has potential to be very useful as a decision making tool in public forest management, this potential has not yet been realized because of the model's tendency to be overly large and comprehensive. To be useful the model needs to be used for more limited purposes in more simple and smaller forms. In addition, the FORPLAN tool should be supplemented with a variety of more specific analytical tools that have tactical and on-the-ground applications."

Sessions (1987), in contrast, made these closing remarks:

> "...I must conclude there is general agreement that FORPLAN has made a significant contribution to forest planning. The economists, the ecologists, and the managers here have largely been satisfied by the ability of FORPLAN to adequately represent their concerns and address issues at the forest level. Over the last several days I have played the devil's advocate to draw out criticisms of FORPLAN and the criticism is surprisingly mild. Perhaps we are exhausted after 10 years of planning?"

My conclusion, based on these reviews and my own experience, is that FORPLAN is a useful and legitimate tool for continued use in Forest Planning. Needless to say there is still room for improvement and this will be addressed in the second half of this paper.

The Case for Using FORPLAN in Plan Implementation

Careful examination of plan implementation reveals that the process is virtually the same as forest planning. The major difference is in the scale of the analysis and the detail of the results. Analysis for plan implementation should result in enough detailed information to allow people at the district level to carry out projects as well as disclose site specific environmental consequences. For example, in FORPLAN, you may substitute project areas (e.g., cutting units) for analysis areas to achieve more spatial detail. Model formulation changes can also be made to assist with plan implementation. Adding adjacency constraints and transportation network formulations helps perform project analyses on subunits of a forest ranging from 10,000-50,000 acres in size. Therefore, with minor modifications of information used and model formulations, implementation analysis can be conducted using FORPLAN (see example 3 for more details).

It is also important to note that much of the information used by national systems is implementation and monitoring oriented, for example, the Resources Planning Act (RPA), Land Management Planning (LMP), and Program Development and Budgeting (PD&B), Joint Data Base (DB), Timber Sale Program Information Reporting System (TSPIRS), Sale Tracking and Reporting System (STARS), etc. The general framework proposed below is applicable at all levels of planning.

Assumptions

In addition to the presumption that FORPLAN is a good tool upon which to improve, the following assumptions are also made in developing problem resolution criteria.

1. The Forest Service will continue to do long range forest planning of some sort.
2. Long range forest planning will incorporate an analytic approach.
3. Planning analysis requirements will not lessen but may even increase.
4. Limited funding and personnel ceilings will make formally trained analysts scarce.
5. There will be a dramatic increase in hardware, software, and communications capability in the next 5 years (Chi 1985).
6. Information flows are in response to decisions being made and their attendant documentation.

Criteria for Analysis and Analysis Tools

Given the problems facing the Agency, analysis performed in the future will have to meet certain criteria to be successful. This is by no means an exhaustive list but includes some criteria considered critical.

Analysis Criteria

1. A clear statement of the role of analysis in forest planning.
2. Simplified acquisition of production and economic information.
3. Solutions that have more spatial content.
4. Models designed to address critical issues.
5. Management realization that size and complexity of models is an investment decision.
6. Help for analysts and managers understanding model results.

All but the first are self-evident. During the first round of planning, the role of analysis was not crystal clear. Many hoped that FORPLAN would provide not only long range analysis, but project level analysis as well. In other words, planners and managers hoped FORPLAN results could be taken to a ranger and the ranger would know what, where and when things needed to be done on the ground. There was also an objective to reduce the amount of NEPA documentation required when implementing projects. Although a couple of forests succeeded in this goal, most were unable to get the kind of spatial detail in the model they desired. The limitations were twofold: limits on model size and the cost of solving large models.

In the meantime, as forests began implementing their plans, they discovered that the projected outputs were estimates and had to be treated as such. The thrust of plan implementation has evolved to managing acres within the approved standards and guidelines. However, it would be naive to think output estimates can be ignored altogether. Some constituents place a lot of importance on these figures. We also learned that the NEPA requirements for project implementation would be overwhelming if done at the forest level. Add to this fact the analysis results contained only part of the information necessary to select a preferred alternative, and it becomes obvious FORPLAN did not provide all of the answers.

Together, these trends have led to the following role for analysis in the Forest Service. Analysis is used to aid decision making. It provides information to decision makers, so they have a better understanding of the implications of their decisions with the goal being improved management. Furthermore, in the forest plan context, the analysis results can be viewed as a zoning of the forest with the schedule of activities and outputs representing anticipated outcomes of such a zoning under an assumed level of management. Finally, the role of forest plan analysis is a strategic analysis. We acknowledge additional environmental analysis will have to be done before site specific projects can be undertaken (in this context analysis does not necessarily imply using a computer). Given the role and the analysis criteria, there are criteria analysis tools must meet:

Criteria for Analysis Tools

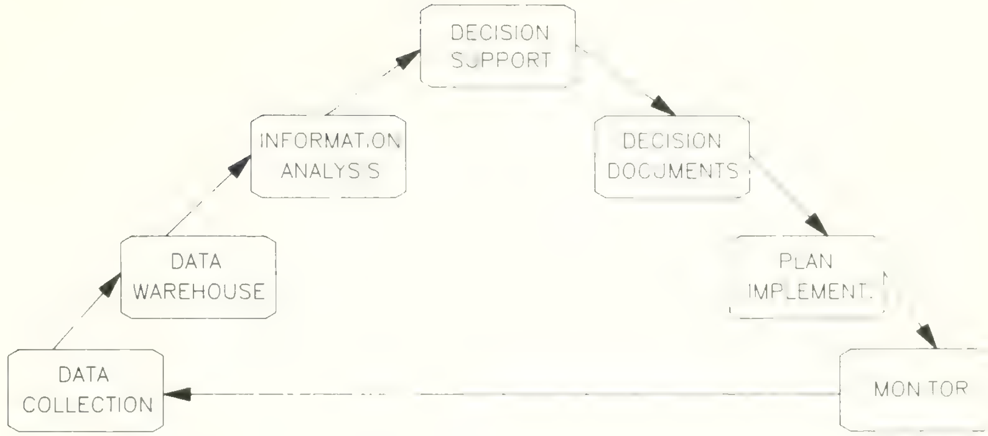
1. Provide assistance in choosing the best tool to address problems.
2. Provide assistance in understanding model results.
3. Provide assistance in creation of analysis data sets.
4. Provide assistance in understanding linkages that need to be made in analysis data sets to achieve desired results.
5. Simplify acquiring production and economic information.
6. Simplify the relation of analysis results to other agency data bases and reports.

A FRAMEWORK FOR ANALYSIS IN THE FOREST SERVICE

Simplifying Analysis in the Forest Service

In this section of the paper, I will outline a framework for analysis in the Forest Service. It is designed to address the stated problems within the criteria which have been developed. The framework accommodates the short term needs of the Agency while allowing the flexibility to adapt to new planning analysis

tools as they become available. Briefly, the framework is based on a foundation of organizational information management. A broad view is taken of the planning problem rather than focussing merely on decision support systems. Three major areas for improvement are identified: (1) improving information flows, (2) simplifying use of tools, and (3) helping people use tools more effectively.



EXAMPLES OF TOOLS USED TO PROCESS, ANALYZE AND STORE INFORMATION IN FOREST SERVICE PLANNING.

INVENTORY	PERM PLOT	GIS	FORPLAN	FOREST PLAN	GIS	TRACS
STND EXAM	TMIS	GRO & YLD	IMPLAN	EIS	FORPLAN	TSPIRS
FINSYS	IRIS	IRIS	SIMULATION	EA	SIMULATION	JOINT DB

Figure 1.--Information flows in Forest Service planning.

Improving Information Flows

A major time-consuming job during the first round of planning was the collection, organization, and analysis of resource data prior to being entered into FORPLAN. Not a lot of attention was paid to this problem at the national level, because each region was organizing things differently, and we were busy refining FORPLAN. Now, however, the climate has changed. We have a standard computer system, work is underway on a corporate information structure, and there are many standard data bases and reports in place. The corporate information structure is intended to provide a data and information base which is easily understood and shared by all users. It is predicated on a corporate information base, data standards, common data definitions, and a technology to support information flow (Rains 1987). Such a climate has a major impact on how we should proceed with analysis in the Forest Service. If a corporate system is in place, then the analysis tools can capitalize on the standardization; and some real efficiencies can take place in information management. Such an approach will greatly reduce the unending translation of information which has taken place in forest planning.

Therefore, the time is right for examining planning information flows with the goal of integrating them into the corporate information structure. Once this is accomplished, tools can capitalize on common data structures and definitions. This approach has a big payoff in terms of simplifying the collection of information for analysis. Furthermore, it is a step toward standardizing information definitions so analysis results aggregated at higher levels of the organization can be used effectively. A simple view of the information flows in the planning process is shown in figure 1. An important point is that a system such as FORPLAN resides in only one box of this diagram. There is a large complex of information needed to support the analysis. In turn, the analysis results are used in many ways within the Agency (fig. 1, table 1). Both points relate to how we can improve forest plan analysis. Clearly, the quality of analysis depends on the information feeding into it. Simplifying the movement of information into analysis tools will dramatically reduce the time it takes to build forest planning models. For example, being able to create analysis areas automatically from a Geographic Information System (GIS) would save a substantial amount of time (Rains 1987). The quality and usefulness of information reported to our constituents and to other levels of the organization also depends on the ease and consistency of reporting. Finally, our ability to learn and improve information and management depends on closing the feedback loop through the monitoring process. Thus, one major component of simplifying and improving planning analysis is to simplify and improve information flows.

Simplifying Use of Tools

The second major area of improvement is to simplify the use of each part of the overall planning system. For example, within the Decision Support Box (fig. 1), FORPLAN can be improved by making it easier to use. An obvious improvement is to have input screens for parts of the data input. This can be done either through screen generating software or by using a data base management system front end (Bevers and Kent 1988). However, as described above, major parts of the input such as the analysis areas and yield tables actually come from other data bases. Here, improvements can be made in supplying yield information in FORPLAN format as output from simulation models (see the examples in later sections of the paper).

A not so obvious improvement, but perhaps the improvement with the biggest payoff in terms of quality of analysis,

Table 1.--Forest Service tools used to process, analyze and store: information in Forest Service planning.

System Name (or Acronym)	Description
1. Inventory	Forest level timber inventory data.
2. Stand Exam	Stand level timber inventory data-usually for projects.
3. FINSYS	Software to summarize and report inventory data.
4. Permanent Plot	Data base for storing permanent plot inventory data.
5. TMIS	Timber Management Information Systems (data base).
6. GIS	Geographic Information System.
7. Growth and Yield	Any one of several timber growth and yield simulators, e.g., PROGNOSIS.
8. FORPLAN	Forest Planning Model (linear programming).
9. IMPLAN	Economic Impact Assessment Model (input-output).
10. TRACS	Timber Activity Control System (data base).
11. Simulation	E.G. DYNAST, Mark Twain N.F. Simulator, Project Area Scheduling System (PASS).
12. TSPIRS	Timber Sale Program Information Reporting System.
13. Joint Data Base	RPA, LMP and PD&B Joint Data Base.

would be an advisor to help users formulate and construct a FORPLAN data set. This can be done through a combination of an expert system and data set templates.

The experience we have gained from past analyses indicates there are certain capabilities most everyone needs for forest planning analysis. Examples of these capabilities can be included in data set templates. Likewise, for implementation analysis, model templates can be constructed which provide the basis for forest analysts to construct customized forest models.

Another improvement with a large payoff, especially considering our new user community, is an advisor to help explain results. Many have suggested the results of planning analysis are difficult to understand. Yet, a competent analyst can explain and understand the results. If we can capture the expertise of competent analysts, other users will have assistance in understanding and interpreting results.

There are certain key indicators which can be used to test for reasonableness and to explain changes, for example, timber inventory at the beginning and ending of the planning horizon, long term sustained yield capacity, and acres allocated to key management emphases.

Helping People Use Tools More Effectively

Simplification is not the only issue however. Analysis must be tailored to the issues facing the forest. I have seen improvement along these lines in recent modeling efforts. However, analysts are still grappling with spatial resolution versus modeling size problems. Some suggestions have been made on how to reduce model size while placing the emphasis on the short term (Barber 1986, Bowes and Krutilla 1987). One approach ignores the problem of scheduling management prescriptions by geographic area, while the other puts the burden of developing a coordinated schedule on the user (Johnson et al. 1986). Neither approach is the ideal. What we would really like is the ability to develop schedules, at least for the short term, by geographic area. If we expect the user to develop coordinated schedules, we find it is labor intensive and subject to criticism for not being comprehensive. Instead, I am suggesting unique analysis areas be developed by geographic area for critical areas.

The approach outlined capitalizes on the ability of computers to deal with combinatorial problems. Software can be developed to facilitate the input burden which might otherwise be imposed on the user. The generalized Model 2 structure of Version 2 FORPLAN can then be used to collapse the spatial detail after the second period. Analysis areas that are harvested are sent to collapsed regeneration classes as usual. The difference is existing stands not harvested within the first two periods would also be collapsed spatially to reduce model size.

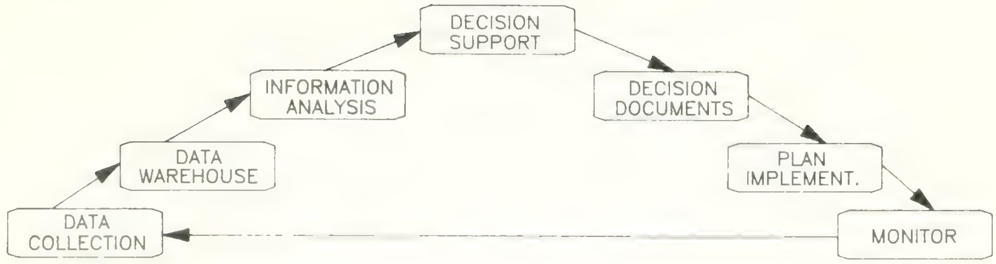
Although resulting models could be approximately as large as current models, the results would provide valuable spatial detail in the schedule. This simplifies the step of checking implementability, makes results much more meaningful to district rangers, and saves time in the overall planning process. Moreover, it allows geographic specific constraints (e.g., habitat dispersion) to be applied to models. Similarly, geographic specific economic information, such as haul costs, can be more readily incorporated into the model. Examples of this type of model formulation must be made available to users so they can start well up on the learning curve of providing useful analysis.

Anticipating the Future

Object Oriented Design

In addition to simplifying model construction using existing tools, we must prepare for changes in tools as improvements are made. This fact argues for a modular approach allowing the modules to be replaced without disrupting the entire information flow. Object oriented programming embodies concepts such as these and may be a useful paradigm for the system development (Coulson et al. 1987, Gomsi and Desanti 1987). An example of the advantages of this approach is in the development of a user interface for the analysis module. The

interface can be common for several different analysis tools, (e.g., simulation and optimization). An expert advisor would lead the analyst through a sequence of questions to pick the best tool for the current problem. Once the tool is selected, a tool specific advisor helps the user construct the actual model. As new analysis tools are developed, they can be added as an option or substituted for obsolete tools. Such an approach has a high payoff, because the majority of the information used in analysis, no matter what tool is used, is the same (e.g., economics, activities, outputs, production relations, management requirements, etc.).



EXAMPLE 1. FLOW OF INFORMATION INTO THE DECISION SUPPORT SYSTEM.

INVENTORY STND EXAM	INDIVIDUAL TREE DATA	PROGNOSIS	FORPLAN YIELD TABLES	FOREST PLAN		

EXAMPLE 2. AGGREGATING INFORMATION FOR HIGHER ORGANIZATIONAL LEVELS.

				FOREST PLAN	IMPLEMENT. ANALYSIS	JOINT DB

EXAMPLE 3. DISAGGREGATING FOREST PLANNING SOLUTIONS FOR IMPLEMENTATION.

INVENTORY STND EXAM	INDIVIDUAL TREE DATA	PROGNOSIS	FORPLAN YIELD TBLS ADJACENCY RELATIONS	EA	TIMBER SALES	STARS

Figure 2.--Examples of improving the planning and implementation process.

The Hardware Dilemma

Another major tenet of the framework being proposed here is modules should be designed, to the extent possible, to be hardware independent. The important decision is to choose hardware which has the capability to perform the needed function efficiently. While this sounds trite, many analysts have been interested in a micro version of FORPLAN (Johnson 1986). Presently, the micro version will not generally handle real problems, even at the implementation scale, because of limits in Linear Programming (LP) algorithms. This is not to imply a matrix might not be generated on the micro and transferred to the mainframe, solved, and a compact report returned to a micro or Data General (DG). Rather, I am implying in the short term, micro computers are not the answer for useful FORPLAN analysis. Given the shortage of processing power on the Agency DG systems, we will opt for a dual strategy which will allow a common front end to run on either the DG or a micro. Eventually, we anticipate that micro computers will be able to solve our problems and this approach incorporates that eventuality.

EXAMPLES OF IMPROVING THE PLANNING AND IMPLEMENTATION PROCESS

To clarify the general concepts described above, several specific examples illustrating improved information linkages with decision support tools will be presented. The illustrations demonstrate how timber information flows from raw stand information to information used in plan implementation and to information used at the National level.

Example 1. Flow of Information into the Decision Support System

Most forests must take a careful look at their timber program in forest planning, both to satisfy the intent of NFMA and to address public issues. Typically this is accomplished by identifying lands potentially suitable for timber management and for management of other resources using timber harvest. Next, prescriptions are developed which define different sets of management objectives for the lands. In turn, activities for achieving the objectives are identified and the outputs and environmental effects of the activities are estimated. If, for example, timber management practices are used, one of the outputs will be timber volume. The question is, given a set of management practices, what volume will be produced? (Realize here that I am narrowing the focus to a single resource for the purposes of illustration.)

PROGNOSIS (Wykoff et al. 1982) is a stand simulation model of the single tree type. It provides yield projections with or without management for existing or regenerated stands. In the first round of planning, the Interdisciplinary (ID) Team generally defined the prescriptions and then a silviculturist would run PROGNOSIS to develop yield projections within the assumptions of the prescriptions. The results of the PROGNOSIS runs had to be translated into the proper format to be entered as yield tables in FORPLAN. Some Forests probably did this manually, while others used computer programs. Although there are many ways to create FORPLAN models and .timber yield tables, there is enough commonality in the way most forests have approached the problem to warrant development of generalized software to facilitate the translation (fig. 2).

Example 2. Aggregating Information for Higher Organizational Levels.

A second example is the PD&B, LMP, RPA Joint Data Base. A project is underway in our Washington Office to create a common data base for these three planning functions. Congress is interested in how budgets relate to implementing forest plans. In addition, they are interested in how forest plans relate to RPA. The goal is to use common data definitions to achieve consistency among the three planning functions, to reduce the number of information requests to the field, to improve integration and information sharing among the three staffs, and to satisfy all information requirements. Presently all Forest Service Regions are meeting these information requirements in different ways. The plan is to develop a Structured Query Language (SQL) data base with a common set of information. Much of the information included has its origin in forest plans. The information required by the planning function, in fact, comes directly from forest plans. RPA information generally requires some amplification from the preferred forest plan alternative, while PD&B information generally requires some refinement. The refinement normally takes place during implementation analysis and when developing program budgets. In all cases, the base information is derived from the plan. Thus, there is an opportunity to provide tools for moving, in an automated fashion, information from FORPLAN solutions to the joint data base. Again, this would be a labor-saving enhancement and would lead to more consistency in the results (fig. 2).

The National Computer Center at Fort Collins (NCC-FC) is planning to build a system to facilitate information sharing and handling among data bases between the DG and the mainframe (USDA 1988). Features of the system are:

1. Menu architecture for applications development.
2. Forms design facility.
3. ANSI Structured Query Language (SQL).
4. Integrated data dictionary.
5. Report writer.
6. Data base administration utilities.
7. Security facilities.

Such features could help move plan information from the mainframe to the Joint Data Base on the DG. In a similar fashion such a system may facilitate plan implementation where much of the information is on the mainframe.

Example 3. Disaggregating Forest Planning Solutions for Plan Implementation

Heretofore forests have faced a significant challenge once they selected their preferred forest plan alternative. The challenge was to disaggregate the FORPLAN solution to the ground such that they knew where the scheduled activities should occur (Keller 1986). Many strategies have been adopted for solving this problem from simple to sophisticated. The approach described here has several features to help address this problem. First, the proposed mathematical formulation (see Helping People Use Tools More Effectively) will allow a more site specific solution. The intent is to obtain activity schedules by user defined geographic areas. Beyond this is the notion of adapting the forest-wide FORPLAN data set to site specific models to perform what is known as area analysis for project analysis and scheduling (Ryberg and Gilbert 1986). Fairly simple modifications to the forest-wide data set results in an area analysis template which can then be adapted to each area where optimization analysis is needed. All that must be added are the project areas (e.g., cutting units), proposed roads, adjacency relationships (if appropriate, Meneghin and Jones 1988), output targets (e.g., desired volume for the area), and standards and guidelines (often in the form of constraints). In addition, some yield estimates may be refined either by including site specific yield data or by refining the PROGNOSIS runs to more accurately represent the site (fig. 2).

Consider the case where during project analysis a timber sale is identified as necessary for implementing the forest plan. The timber sale is entered into the Sale Tracking and Reporting System (STARS). The NEPA process is used to provide public notice and comment. When the decision is made an appropriate NEPA document is produced [Categorical Exclusion (CE), Environmental Assessment (EA) or Environmental Impact Statement (EIS)]. STARS continues to be used to track the sale until a contract is awarded. There is an opportunity to automate the link between the project analysis and the sale tracking system. The benefit would be a reduced workload for district resource managers.

But, suppose a sophisticated tool such as FORPLAN is not needed. This is the problem an advisor is designed to solve. It helps the user examine the problem at hand to determine what level of analysis is necessary and appropriate. Various levels of tools should be available from simple economic calculation programs to sophisticated simulation models. The user selects from an array of tools the one that best analyzes the current problem.

SUMMARY AND CONCLUSIONS

Significant opportunities exist for simplifying and improving analysis in the Forest Service. Foremost may be an improved understanding of the role of analysis in forest planning. Next, the realization that the tools we have available meet our analysis needs. However, improvements need to be made along three fronts: (1) improving the flow of information from information sources to analysis tools, (2) simplifying the creation and use of analysis models, and (3) making the analysis results more useful. By accomplishing these tasks within the criteria outlined above, we will make large strides toward solving the

problems discussed at the outset. Even though the analysis will probably always be criticized for political reasons, at least now the results will be more useful, more understandable, and more easily accomplished. A simple approach to analysis will continue to be our goal. However, when problems require sophisticated analysis for solution, we will help guide analysts to use the proper tools. Furthermore, if the whole analysis process is made easier and faster, reluctance to its use will diminish. Software and hardware technology hold promise for making these improvements now. It is imperative the Forest Service undertake these enhancements so we can improve the next generation of analysis based on the lessons learned from our past experiences.

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Design Considerations for LP-Based Forest Planning Systems: Perspectives from FORPLAN

Brian M. Kent and Michael Bevers[1]

Abstract.--Over the past decade FORPLAN has evolved into a large and complex linear program modeling system for decision support in forest planning. Although FORPLAN employs a highly sophisticated data deck design and reporting system for card image batch processing and high speed printing, recent strides in user interfaces on desktop and office machines present new opportunities for future planning systems. Design considerations for this new processing environment, including possibilities such as an interactive desktop data set manager, a mainframe batch submittal system, dynamic core allocation, heap storage, and flexible array packing, are discussed.

Since the late 1970s, the USDA Forest Service has been heavily involved with the development of multiple-use land management plans. This activity has been conducted in compliance with the National Forest Management Act of 1976 and its attendant regulations (USDA Forest Service 1982). Early on in this activity, the role of a linear programming (LP) based system, FORPLAN, as principal analysis tool was established.[2]

Experience with this first version of FORPLAN led to the development of a second version in 1982 (Mitchell and Kent 1987). Because the relevant background information has been covered elsewhere, we will not provide a detailed discussion in this paper. An excellent account of the evolution of both versions can be found in Iverson and Alston (1986). For additional information on the evolution of FORPLAN, as well as descriptions of each of the versions, refer to Johnson (1986) for an overview of FORPLAN Version 1 and Johnson et al. (1986) for an overview of FORPLAN Version 2. Descriptions of the technical criteria used in the development of FORPLAN be found in Jones (1987) for Version 1 and in Weisz (1987) for Version 2. Details on how FORPLAN was used for national forest planning applications can be found in the two overview documents cited above, as well as in Mitchell and Kent (1987).

Much of the early development of both versions was done by Dr. K. N. Johnson, now at Oregon State University. However, as Mitchell and Kent (1987) point out, after this initial work, additional development, user support, training, and system maintenance responsibilities were taken over by Forest Service personnel (specifically by the Land Management Planning Systems Section in Fort Collins, Colo.). During the 8 years the Systems Section has functioned in this role, considerable experience in various facets of the FORPLAN system has been gained. One of these facets related to questions of overall design for an LP-based planning system such as FORPLAN. The purpose of this paper is to provide a discussion of some of the potentially more significant ideas for system redesign. Simply put, given the lessons learned from this experience, "where might we go from here?"

Background and Organization

Much of the FORPLAN systems work done by the Forest Service has been guided by two principal objectives (Gast 1986):

1. Simplify and enhance the system, and
2. Reduce run costs.

It seems logical to assume that these objectives will continue to be of concern. Although they can be and often are conflicting,

[1]*The authors are, respectively, Research Forester, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, 240 W. Prospect, Fort Collins, Colorado 80526, and Computer Specialist, Timber Management and Land Management Planning Systems Section, USDA Forest Service, 3825 E. Mulberry, Fort Collins, Colorado 80524.*

[2]*USDA Forest Service. 1979. Letter from Douglas R. Leitz, Associate Chief, to Regional Foresters and NFS Directors. 1920: Development and use of forest planning model. December 3.*

it is reasonable to specify a goal that the redesign ideas discussed below be directed towards providing efficient modeling capabilities to the national forest planners.

As a framework for our discussion, we make the following assumptions about future national forest planning activities:

1. LP will continue to be the central analysis tool used.
2. Models will continue to be very large and complex. Criticism about size, cost, and complexity (Bare and Field 1987) seem to be offset by criticism calling for more spatial detail and site-specific analysis (Shugart and Gilbert 1987).
3. The recent achievement of significant advances in the whole arena of computer science will continue.

Chi (1987) gives an excellent description of implications of computer related advances. He identifies seven significant trends, two of which, and especially the second, have particular significance to much of what we discuss below. The first of these trends Chi refers to as, "sustained exponential price-performance increases." The major significance of this trend for our purposes stems from the fact that both new and powerful hardware environments (e.g., distributed systems, intelligent work stations, and micro computers) and new and different software applications are now possible.

The second trend relates to what Chi calls a change in objective function. Specifically, he states:

> "...the objective for the first 20 to 30 years in computing was to maximize systems performance. In contrast, the objective function today is to maximize user performance."

On the hardware side, the new environments mentioned above made computing and computers available to many, including those with no prior experience.[3] Demand for and interest in using computers increased with this availability and a primary focus became making things easy for the neophyte user. Many of these efforts involved the development of what has become known as "user friendly" software. A real problem is the fact that, as Chi (1987) points out, it takes a tremendous amount of computer and manpower resources to develop and operate effective user friendly systems.

We will use Chi's trends to refine our efficiency goal by considering both system and user efficiencies in developing redesign ideas. From this point on, we will assume that FORPLAN Version 2 (henceforth FORPLAN) is the system of interest. FORPLAN, like many other systems, evolved in what might be termed a traditional mainframe environment where the focus was on system efficiencies rather than user efficiencies. Because of this, it is reasonable to expect that significant gains in user efficiency can be made with FORPLAN in an interactive distributed workstation environment. It is important to recognize that, as Chi (1987) points out, there will be a significant price to be paid in terms of increased system size--a price that will manifest itself in terms of both computer and maintenance resource requirements. This suggests the existence of a tradeoff between system and user efficiencies.

An example of the implications of this tradeoff can be found in the FORPLAN evolution that has already taken place. FORPLAN Version 1 had an input data organization and input procedure that was very difficult for users to understand (Weisz 1987). In an effort to resolve this, a different set of data input and organization conventions known as DE FORPLAN was developed. While this approach alleviated some of the earlier problems, it left users with data sets containing up to 2.5 million card images. The user was thus overwhelmed with the care and feeding of unmanageably large data files. This problem was resolved with redesign efforts that went into FORPLAN Version 2; however, the resultant changes in system size were significant. The DE FORPLAN code required about 65,000 words of main memory to execute while the enhanced code requires almost the system limit (under UNISYS Corp. Operating System Exec level 39) of 262,000 words. The number of lines of executable source code requiring maintenance increased from around 5,000 to 36,000.

Three additional factors that will influence FORPLAN users and their environment merit mentioning here. The first is that our assumption about the continued development of large LP models has important implications for the tradeoff between system and user efficiencies. It will not be feasible for several years to solve these large models on workstation equipment. Thus, model solution will still require centralized processing and support. The significance of this is that in order to enhance user efficiency, FORPLAN jobs will likely have to be partitioned among two or more systems in the future. The second factor is that the situation with FORPLAN differs in one detail from the first trend described by Chi (1987). This difference is that, unlike overall industry costs, mainframe processing costs on the USDA UNISYS computers have not decreased significantly over time. We surmise that this is because they primarily support costs. The third factor that will play a role in system enhancement, and this is true for any system, is the software development lag. Software development projects, such as new operating systems, etc., typically run 100% over budget and a year behind schedule (Carroll 1988). This becomes critical when enhancements to a system like FORPLAN are dependent on capabilities that must come from software developed by others. As an example, to function effectively on a micro computer, FORPLAN requires an operating system that can address more than 640 Kbytes of main memory (the limit for MS-DOS). An operating system with this capability has been promised for 2 to 3 years and is just now becoming a reality.

An important implication of the above seemingly disjoint collection of observations is that any redesign efforts for FORPLAN cannot afford to focus solely on user efficiency. System or code related efficiencies must also be considered and the tradeoff between the two mentioned above is very real. The organization of the remainder of this paper attempts to reflect

[3] Our interpretation of this cause and effect relation differs somewhat from Chi's in that the suggests that the focus on the user is the driving force behind the change from centralized to decentralized computing.

this. The next section will consider redesign ideas that enhance user efficiencies. The following section will serve the same purpose for system efficiencies and the final section will look into the question of the development of linkages between FORPLAN and other systems.

Redesign Considerations for Increased User Efficiency

In this section of the paper we focus on three opportunities for redesign efforts leading to increased use efficiencies. The first relates to user interfaces with FORPLAN input data sets, the second to user interfaces with FORPLAN solution reports, and the third to FORPLAN run preparation and submittal.

As has been pointed out, data is currently input in a card image format. In addition, the organization of this data, while improved over that of Version 1 and DE FORPLAN, is still difficult for users to understand. As a result, data preparation and development of an understanding of the linkages between different data types are difficult tasks for many users. Currently, data sets are developed with some type of text editor, with only written documentation, format instructions, and previously developed data sets available for guidance. The only way to verify correct data set development is by processing the data against the matrix generator's data interpretation and error checking routines in a batch run. As if these problems were not enough, the information provided by the matrix generator comes in the form of a large (often more than 1,000 pages) hard to read batch printout.

Major (and interrelated) problems faced by a FORPLAN user in this environment include the following:

1. It is difficult to develop and debug data sets, especially if any of the more refined FORPLAN system modeling capabilities are incorporated.

2. The task of data verification is difficult and often not completely carried out. This is caused in part by the fact that the user has access to many optional features and a complete bullet proofing in the matrix generator against all possible errors is not feasible.

3. There is a real danger that users become so involved with the data error elimination game that they never develop an adequate understanding of how to use and/or revise their data in order to adequately model and analyze their problems.

4. A very steep learning curve must be faced by anyone new to using FORPLAN even if he or she has an existing data set and FORPLAN analysis results to work with.

Two approaches can be taken to partially resolve some of these problems by moving away, where possible, from a batch processing environment and all that it implies. Complete resolution, however, is not likely because of the complexity of the forest planning application. The first approach involves development of software that permits data set development in a user friendly interactive environment. Key improvements of such a system would include data entry screens, on-line help capability, and interactive data set debugging facilities. These components would be designed so that the user could build a data set in a modular fashion using interactive help and error checking features. FORPLAN data sets are frequently modified and this activity would be facilitated by this type of interactive environment. Because of the complexity of FORPLAN data sets, this system would not be easy to develop and, in addition, modification of both the matrix generator and the report writer would be necessary to incorporate the necessary data set modularity.

An alternative approach would involve the change in thinking implied by changing the term data set to data base. The key element of this approach would be the development of an interactive data set manager. This tool would be used to develop, debug, and/or modify a FORPLAN data base. In addition, this approach would provide the user with query capability. As an example, a user might want a list of all prescription decision variables on an area of the forest that link to a particular constraint. Most likely, this data base manager would be developed as a relational data base (Codd 1970), although the hypertext approach (Goodman 1987) expert systems (Partridge 1986) and object oriented programming (Gilbert this proceedings) also offer some promise. While these approaches differ in detail, they all offer the user the ability to organize and view data in forms that make the data items, their organization, and linkages more intuitive. The payoff is an increased understanding of what needs to go into a FORPLAN data set in order to do effective analysis.

The next area that has potential for increased user efficiencies is that of FORPLAN solution reports. As is the case with the matrix generator and data development, solution reporting is done for the most part in a batch processing environment, often resulting in large printouts. The current report writer uses the same input data as does the matrix generator and offers reasonable flexibility in terms of user report selection. However, as Bevers (1986) points out:

> "A shift in computer programming emphasis from specialized, mainframe-based reporting systems to more generic, transportable programs which primarily provide linkages to other software is an attractive change whose time has come for the Forest Service. Today's commercially available software packages for charting, graphing, and other reporting are both powerful and easy to use."

Users often need either additional analysis of solution results for such things as plan implementation or more refined reports than FORPLAN can produce. Until recently their only alternative was to develop their own utilities to process the input data and solution reports. In 1986 a flat file reporting capability (Bevers 1986) was added to the report writer. This enabled the user to generate solution reports in a form that could be

transferred to a Data General minicomputer and processed against Data General "Present" report writing software.

The flat file capability offers a partial solution to the report problems mentioned previously. However, a more general and potentially useful alternative exists. This would be to generate solution information in relational data base form and then use a structured query language processor to develop the desired reports or additional analyses. Note that this solution is similar to one posed above for input data problems.

The final area for potential user efficiency increases is that of FORPLAN run submission. As alternatives to the mainframe (such as mini- and micro-computers) become more available, and as user friendly systems such as those discussed above are developed, more and more FORPLAN jobs will be run on multiple systems. As an example, a particular job might consist of data construction, matrix generation, LP model solution, and then solution reporting, with the first and last steps being done on a mini- or micro-computer and the LP generation and solution being done on a mainframe. When a job is partitioned across more than one system, a considerable amount of file transportation and job control language interfacing (usually with more than one operating system being involved) is necessary. To make all of this easy, a job submittal software system that would insulate the user from dealing with all of the details would be most desirable. The user would interface interactively with this software on the hardware system of choice (likely Data General mini-computers in the Forest Service). He or she would only need to specify the type of job, the information specific to this job (i.e., the location of input data files, etc.), and possibly the nature of the job partitioning. The batch runstreams necessary to actually execute the job and transfer files between systems would be built and executed by the submittal system.

Processing Efficiency Considerations

As was pointed out earlier, FORPLAN has grown immensely in recent years as the Systems Section has tried to accommodate requests for new modeling features and tried to make the system easier to use. FORPLAN has become too large and too expensive to ignore processing efficiencies, and the user-oriented redesign proposals outlined in the preceding section could further exacerbate this problem if not carefully implemented. At the same time, opportunities for improving the current processing capabilities should be explored as well. Consequently, efficient approaches to job partitioning and memory management warrant examination.

The typically large sizes of national forest planning models suggest a logical approach to job partitioning. As Kent et al. (1987) point out, these models commonly range in matrix size from 100,000 to 3,000,000 non-zero LP coefficients. Even if micro-based workstation CPUs, IO transfer rates, and mass storage devices could satisfactorily support the number crunching and file addressing demands of such models, the need currently to upload the problem to a mainframe computer for LP solution makes it impractical to generate the matrix locally at a distributed processing site. The prospects for telecommunicating hundreds of thousands of LP matrix records per model are simply not good. While it is desirable to move the jobs of building, debugging, and storing the model data, as well as interpreting solution results, onto local workstation equipment, both matrix generation and LP solution will continue to require mainframe resources in the near future.

Although FORPLAN jobs could be partitioned in this fashion by just building new workstation tools without modifying the mainframe system significantly, there are some advantages to redesigning the mainframe code. Such tasks as card image transfer and processing could be reduced, and redundant tasks, such as data error checking and matrix printing could be eliminated. However, the big payoff to revising the mainframe code would be in enhanced memory management.

The data set management and job submittal system software proposed in this paper could handle not only the principal model data, but by storing appropriate counters and array pointers, could manage memory allocation parameters for the receiving mainframe system. Ideally, the submittal system could send the mainframe host a FORPLAN job with a mixture of "core images" for common array and pointer values, card images for analysis area lists, directly entered prescriptions, and yield tables, and a set of model parameters for memory management. As an example, a principal model parameter to pass would be the total amount of computer memory required to process a particular model. This would provide a fast-loading system that could streamline processing through dynamic core allocation, heap storage techniques, flexible packing schemes, and common-banked instructions.

Dynamic core allocation would give FORPLAN the ability to have each model occupy exactly the amount of core memory required for that model. Currently, all FORPLAN models, however small, occupy 256 Kwords of main memory, or about 1 megabyte. Through dynamic core allocation, system impacts and user charges for smaller models could be greatly reduced.

In order to support dynamic core allocation, both heap storage techniques and flexible packing schemes would be desirable. As FORPLAN has grown and matured, hard-coded array dimensions (and model section size limits) such as 5 objective functions and 100 activities and outputs have been replaced throughout the system with adjustable size parameters. The parameters allow the variation of size limits and memory allocation much more easily, but only by completely recompiling and collecting the entire source code. Once the parameters are set, that space is always allocated in memory whether needed by a particular model or not. Heap storage techniques employ the use of an increased number of pointer variables to allow maximum freedom within core array space. Thus, if no temporal flow constraints are used in a model, as an example, the pointer would be left null and that array space would not be allocated, leaving more memory available for other model input sections or free core.

As long as memory addressing continues to be more limiting than processor speeds, maximum use of dynamic core allocation will require flexible packing schemes. FORPLAN programmers have increasingly had to employ specialized data packing to keep within existing hardware and operating system limits. However, these procedures for storing multiple values within single addressable storage words of memory currently work from known imposed FORPLAN limits. Since FORPLAN programmers know, for example, that there are only eight thematic identifier levels allowed and that each level may use no more than 100 identifiers then each set of eight identifiers is packed into two 32-bit computer words of storage using seven bits for each level identifier sequential number. If we are to truly remove programming-imposed limits and make full use of dynamic core allocation, these packing schemes must be made both flexible and general. This change would also open the door to increased model flexibility since users would no longer be constrained by programming limits such as eight thematic identifiers levels, but rather by total memory and processing limitations.

Before moving on to common-banked instructions, three final points about heap storage and flexible packing must be made. The first point is that both of these techniques are far more easily and efficiently done in the "C" programming language than in FORTRAN, which is currently used. The second point is that as memory becomes cheaper and more easily addressed (Chi 1987), data packing may become unnecessary and even inefficient. Finally, the ability to gain this degree of memory flexibility is critical to ideas expressed in the next section of this paper.

Impacts on memory resources, and the associated run costs, could also be reduced by moving to common-banked instruction sets. Often in the past, four FORPLAN models have been processing in core concurrently at the USDA National Computer Center in Fort Collins. For each of the models, separate complete instruction banks along with the necessary data banks have been loaded into core. By moving the FORPLAN instruction set into a single shared resident common bank accessible to all users, total memory requirements could be reduced by about 1 megabyte. Each FORPLAN job would be smaller and more easily accommodated in core during peak processing times.

Linkages to Other Systems

In the previous two sections of this paper, we have emphasized the significant time and resource investments needed to learn FORPLAN, to build and debug data sets, to solve the resultant LP models, and to generate and interpret solution reports. Acquisition of the information needed to build or modify a FORPLAN input data set also requires a considerable investment in time and resources.

Mitchell and Kent (1987) discuss the types of information that can be utilized in a FORPLAN input data set. Briefly, the types of information most likely relevant to this discussion are information on land strata and the vegetation occupying them, information on prescriptions, information on costs and returns associated with management practices, and yield information pertaining to production levels of various goods and services. This section of the paper will briefly address ideas that have the potential to increase user efficiencies in the input data acquisition and updating arena.

First we consider data pertaining to the land base and existing vegetation. The basic strata in a FORPLAN model are called analysis areas and are typically defined by combinations of attributes such as current vegetation, slope, soil type, administrative boundaries, etc. There will usually be from 200 to 700 analysis areas defined for a given National Forest and these will be the result of aggregating several thousand more precisely defined land parcels called capability areas.

Up to now, the formidable tasks of defining, locating, and measuring the size of capability areas, of aggregating these into analysis areas, and of incorporating this information in FORPLAN input data have been done largely by hand. In addition, the disaggregation of FORPLAN solution results back to these strata has also been done manually for the most part. A contributing factor to the size of these tasks is that there are often too few direct relationships between FORPLAN layers (identifier or thematic levels) and the layers used to define capability areas.

With the Forest Service moving (although slowly) into GIS technology, there is real potential for increased user efficiencies in this area. First, this will permit automating much of the job of land and vegetative base inventory information management. This is important for many reasons, not the least of which is the ability to quickly update these inventories as a result of plan implementation activities, catastrophes, new information or any other factor that changes this data. Secondly, this will facilitate the development of automated linkages between GIS data bases and FORPLAN analysis area data. As an example, one real plus to the increased user flexibility described earlier in this paper is that with some thoughtful design, the number of FORPLAN layers (currently at most eight are available) could be made more flexible as well. This could provide the opportunity for automated linkages between FORPLAN and GIS layers (or map overlays). The need for thoughtful design of FORPLAN output (be it either on a screen or in printout form) to support this flexibility cannot be overemphasized.

We close this section of the paper with a general observation about the other types of information mentioned at the beginning of this section. The key point here relates to the fact that much of the economic and yield information is generated by various software systems such as yield simulators. There are opportunities to develop linkages between these simulators and FORPLAN data sets. This linkage software could be used to automate development and updating of the relevant sections of FORPLAN input data.

Conclusions

From what has been discussed in this paper, it is obvious that changes in computer technology along the lines of those described by Chi (1987) have the potential to significantly alter and improve the interfaces between users and a large system such as FORPLAN. These changes have great potential for improving the users' lot in life. However, it is important to recognize that while it is relatively easy to outline them conceptually in a paper such as this, actual development of systems necessary to implement the changes will be something else again. The key question is, do the ends justify all the additional work? In our opinion, they do.

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Experiences with FORPLAN--A Distillation to Two Proceedings from a Research Prospective

Brian M. Kent, John G. Hof, and Linda A. Joyce[1]

Abstract.--In 1986, the USDA Forest Service sponsored two meetings focusing on the forest planning tool FORPLAN. The first meeting was an internal workshop addressing the topic of lessons learned during the first round of national forest planning. The second meeting was a symposium involving participants from both in and outside the Agency and its purpose was to provide an evaluation of FORPLAN. This paper contains a review of the proceedings published for the meetings. The focus of this review is on potential research topics that would address problems relating to future planning efforts.

In 1986, the USDA Forest Service sponsored two meetings pertaining to the Forest Planning system FORPLAN. The first was a national workshop that explored the lessons learned in the agency through the use of FORPLAN. The participants at this workshop were almost exclusively Forest Service personnel. The second was a symposium whose theme was an evaluation of FORPLAN. Unlike the workshop, there were numerous non-agency experts and members of interest groups in attendance, in addition to agency personnel. These external experts played the lead role in the evaluation, with background and supporting information being provided by agency experts.

Proceedings of both of these meetings have been published (Bailey 1986, Hoekstra et al. 1987). Both proceedings contain useful information and recommendations on a number of subjects pertaining to National Forest planning, FORPLAN, and the agency's planning process. The purpose of this paper is to focus on one subject, the ideas, and recommendations pertaining to future research and development activities. We will summarize the relevant information from each meeting and then conclude with some general observations. Since the ideas expressed came from a diverse group of individuals both in and out of the agency, particular attention will be paid to any common "themes" or frequently repeated recommendations.

THE INTERNAL WORKSHOP

As is pointed out in the preface (Bailey 1986) the main purpose of the workshop was:

> "...to serve as a forum to share experiences with FORPLAN, to better understand how best to capitalize on past successes and avoid pitfalls as we head into plan implementation, and prepare for the next round of planning."

As this statement implies, while the main focus of this workshop was not research, the potential for the discussion of numerous research related topics was high.

A review of the 33 papers and the recommendations of the three working groups bears this out. We group the problems that were identified into four categories as follows:

1. the agency's planning process, the role of Forest Planning within that process, and the role of analysis in planning;
2. the need to be able to conduct additional analysis, such as sensitivity analyses;
3. the need to improve existing data and acquire new data; and
4. miscellaneous topics such as plan monitoring.

Clearly, these categories are interrelated in terms of their implications for research and we shall point out some of these relationships. What follows is not an enumeration of all references to all problems, but a sampling of references to the most important problems identified by workshop participants.

PLANNING PROCESS/ANALYSIS

This is probably the most important area of concern and to one degree or another, all the other problem areas will be

[1] *Operations Research Analyst, Principal Economist, and Range Scientist, respectively, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO 80526.*

affected by the way in which these issues are resolved. Throughout the proceedings, there is evidence of widespread concern about the roles of both forest planning and analysis. Line officers (Ehlers 1986, Voytas 1986) expressed a concern that FORPLAN is a tool to aid in making decisions rather than the decisionmaker--a point that they feel is often misunderstood. Iverson (1986) points out that both the limits of modeling and the role of models, providing insights instead of answers, are not always as well understood as they should be. Wong (1986) raises the question of how much detail is really required to do forest level planning.

Some of this confusion may stem from the lack of personnel who are well trained in planning and analysis, which is an institutional problem rather than a research question. On the other hand, at least some of it undoubtedly arises from a lack of precise definitions pertaining to the roles of the different levels of planning and the types of analysis that needs to be conducted for each. The first two recommendations from Working Group #3 make this point:

> "The Agency must better define the role of forest planning in the context of the overall planning job for the agency. Once Item 1 is accomplished, the role of FORPLAN and analysis can be more clearly defined and perhaps simplified."

Both of these points suggest research priorities. As an example, there exists a rich body of literature on planning theory that has never been considered by agency planners and analysts. Workshop participants offer several suggestions for research efforts pertaining to the role of analysis and modeling approaches.

Several authors (Barber 1986, Greer 1986, Voytas 1986) stress the need for simpler, more understandable models and approaches to analysis. Troyer (1986) observes that models which are expensive and difficult to use are not what the agency needs and that any system must help accomplish the agency's mission. Of course, the point is also made repeatedly in the two meetings that the development of a multiple-use land management plan for a National Forest is not a trivial exercise and may therefore require the use of sophisticated systems to carry out complex analyses.

Iverson (1986) points out the limitations of mathematical programming as is currently used in FORPLAN, while Stage et al. (1986) suggests that the use of simulation models either with or instead of optimization models be investigated. They also stress the need to improve our ability to incorporate uncertainty in forest planning analysis. Wilson (1986) points out that FORPLAN can be used effectively both as a simulation and an optimization model. Finally, Connelly (1986) and Mitchell (1986) recommend that a multi-stage approach to forest planning be investigated. All of these ideas have potential, but for them to be investigated effectively, the overall agency planning process, the role of forest planning within that process, and finally, the role of analysis must all be more clearly defined and understood.

NEEDS FOR ADDITIONAL ANALYSIS

Within this problem area, three general categories of analy-sis are identified: spatial, sensitivity, and budget level analysis. Spatial analysis is perceived as a problem because it is difficul to represent in a linear programming (LP) model (Connelly 1986). It is, however, an important consideration from the viewpoint of many resource specialists. However, should it be addressed as part of forest planning and/or as a part of plan implementation (Keller 1986)?

The need for sensitivity analysis arises both from the poo quality of some of the data in FORPLAN models and from the problem of uncertainty (Greer 1986, Wilson 1986). Unlike spatial analysis, well known procedures are available for con ducting a sensitivity analysis of an LP model. Such an analysis is, however, expensive and time consuming when conducted on large LP models such as those that are often generated with FORPLAN. Greer (1986) suggests that a formal assessment of agency needs for sensitivity analysis be conducted, that smaller simpler models be used where possible to facilitate sensitivity analysis, and that additional user friendly operations research tools be developed to facilitate sensitivity analysis.

The importance of analyzing the impacts of different budge levels on plan implementation is pointed out by Leonard (1986) while Hof et al. (1986) feel that this type of analysis is critica for the effective use of forest planning information in nationa planning.

REPRESENTATION OF OTHER RESOURCES/DATA QUALITY

This problem area relates to two general concerns, th incorporation of resources other than timber into forest plan ning analyses, and the improvement of the quality of the dat used in these analyses. Leonard (1986) points out that bette ways must be found to incorporate non-priced resources an minerals in FORPLAN models and the planning process. Con nelly (1986) and Lee (1986) comment on the difficulties o representing wildlife and fish resources in FORPLAN.

Troyer (1986) observes that the accuracy of forest plannin data bases must be improved. This point is also the basis of on of the recommendations of Working Group #2, especially i terms of needs for the next round of planning. Concern wa expressed pertaining to the difficulty of estimating benefit (Wilson 1986). He also points out the need to design futur resource inventories with forest planning data needs in mind.

Standardization of FORPLAN models and data is suggeste by Weisz (1986). Working Group #1 recommends that dat standards be developed with particular attention being paid t the need to be able to aggregate information upward within th agency. Hof et al. (1986) point out the need for data and analysi consistency between forests in order to facilitate national plan ning. Standardization may also offer advantages in terms o simplifying analysis. To some degree, data and analysis stan

dardization is an institutional issue, but care must be taken to insure that mindless standardization, at the expense of innovation and creativity, does not occur. Research into how this might be accomplished would be important if standardization is going to be given serious consideration.

Miscellaneous Topics

A few other problem areas that have research implications are suggested by workshop participants. Keller (1986) suggests an approach to plan monitoring that involves the development of a metric to measure the convergence of forest conditions to the desired or steady state condition. Working Group #2 recommended the development of a flexible system for project and plan implementation analysis. Hilliard (1986) suggests that such a system should be developed with the recognition that this analysis will be conducted at the Ranger District Level. Finally, Hagestedt (1986) comments on the importance of retaining records of the experiences and lessons learned by agency personnel during the first round of planning and suggests the use of artificial intelligence systems to help accomplish this.

THE FORPLAN EVALUATION SYMPOSIUM

We now turn our attention to a review of the symposium on the evaluation of FORPLAN. The symposium was organized into three sessions, the first addressing the development and implementation of FORPLAN by the Forest Service, the second recounting experiences in the implementation of FORPLAN by non-agency users, and the third containing the evaluation of FORPLAN including implications for management and research. We will discuss relevant recommendations from each of these sessions, with our primary focus being on the third session.

SESSION 1--FORPLAN DEVELOPMENT AND IMPLEMENTATION

There are three papers in this session which discuss topics that relate to research. The first of these, Teeguarden (1987), provides background information on the adoption of a "rational comprehensive" planning philosophy (Lindbloom 1959) in the National Forest Management Act (NFMA) and its associated regulations (USDA Forest Service 1982). This philosophy has had a significant effect both on how FORPLAN has been used and on the recommendations for research made in the other papers presented at the symposium.

Teeguarden also develops a list of 24 analysis and documentation requirements that result from the NFMA regulations. Nineteen of these are forest level requirements, eight of which FORPLAN can potentially satisfy. These relate to planning alternative analysis, vegetative manipulation, and land allocation. The other 11, relating to nontimber resources, can be partially met with FORPLAN but other models or analytical processes are also needed. The five remaining requirements relate to concerns that go beyond the forest level. Two of these, species diversity analysis and economic impact analysis, can again be satisfied in part, with FORPLAN. The other three, determination of viable vertebrate population levels, federal/state/private coordination, and cumulative effects analysis, lie clearly beyond FORPLAN's capabilities.

Based on all of this, Teeguarden suggests some research priorities. These include the development of improved methods for modeling demand in forest planning, improved methods for viable population determination, and the development of models and analysis procedures to facilitate cumulative effects analysis and coordination with other governmental agencies and the private sector.

Teeguarden closes with some observations on the question "will comprehensive planning work?" He expresses the concern that if it fails, it will be a major setback for the forestry profession. He also stresses the importance of a comprehensive evaluation of what has been done in the first round of planning.

The second paper (DeAngelis 1987) provides a discussion of the first session papers from the perspective of a quantitative ecologist. He addresses four basic issues pertaining to the adequacy of FORPLAN as a modeling framework. These are:

1. the optimization approach,
2. linearity of models,
3. spatial resolution, and
4. uncertainty.

In terms of optimization modeling, DeAngelis points out the difficulty of representing nonmarket valued commodities and ecological considerations in a model based on a financial criterion of optimality. With regard to linearity, he notes that ecological systems are often highly nonlinear and in fact, under extreme circumstances, may be discontinuous. In such situations mathematical catastrophe theory is suggested as an alternative. The third issue, spatial resolution, is in his opinion, handled to some degree by FORPLAN. However, many important ecological spatial aspects such as landscape heterogeneity are not dealt with adequately. The fourth issue, uncertainty, is difficult to address in FORPLAN models, especially when the size of these models is considered. Sensitivity analysis may partially alleviate this problem, but its usefulness is perceived as limited for large models. He suggests a modification to the FORPLAN approach that permits the selection of suboptimal strategies if they significantly reduce the probability of undesirable outcomes.

The final first session paper discussed is Johnson (1986). While his main focus is on the development of FORPLAN, he does point out a number of problems that could require further investigation. The first problem relates to the question of emphasizing economic efficiency versus estimation of environmental effects. In his opinion, the agency has structured both the

NFMA regulations and its approach to analysis to focus on the former. From an analysis viewpoint, Johnson sees this problem as manifesting itself through the selection of an optimization approach over simulation approaches. The answer to the question of modeling approach is, at least in part, driven by the nature of the planning process (in this case, the NFMA regulations). As was pointed out repeatedly in the internal workshop, both of these questions merit further investigation.

Johnson goes on to point out that the model structures and use of FORPLAN have never been published in the scientific literature. He also expresses concerns both about the survival of integrated planning in an agency organized along functional lines, and about the implications of reduced budgets on plan implementation.

Johnson raises a few additional points. External reviewers of forest plans will be concerned as to whether "efficient" prescriptions are adequately represented in FORPLAN models. Given a definition of "efficient" this area is amenable to research. He notes, as have other authors, the problems of uncertainty and overly complex models. He recognizes that because of the complexity of the planning problems being addressed, it may not be easy to simplify models, but he feels this must be accomplished. Like Teeguarden (1986), he feels that sound cumulative effects analyses must be conducted. Johnson also suggests that the results of analysis and plan implementation could well become important building blocks for the next set of forest plans. This idea (also suggested by West (1986) in the workshop) has intuitive appeal and is another area with research potential.

SESSION 2--EXTERNAL FORPLAN EXPERIENCES

This session contains two papers that address possible research problems. Davis (1987) suggests two relevant research roles for the FORPLAN system. One of these is an investigation of conditions favoring even versus uneven-aged timber management systems. The other relates to the use of FORPLAN to help facilitate coordination of Forest Service planning with that of other agencies and the private sector. Davis also makes the point that FORPLAN could be a very useful tool for conducting policy analysis studies.

Dellert (1987), points out that FORPLAN would be a more attractive system if it could be simplified and easily linked to other planning systems such as a geographic information system. This would form an overall planning system, and such a comprehensive system would undoubtedly be useful to the Forest Service.

SESSION 3--FORPLAN EVALUATION

In this session, FORPLAN was evaluated from three perspectives, economic (Beuter and Iverson 1986), ecological (Shugart and Gilbert 1986), and operations research (Bare and Field 1986). Each of these evaluation papers was accompanied by two discussion papers. We now consider each set of three papers in turn.

The Economic Evaluation

The central theme of Beuter and Iverson (1987) is that a system such as FORPLAN cannot possibly determine a thorough and precise optimal solution to the forest resource allocation problem encountered in Forest Planning. They identify several purposes for such a model that suggest research priorities: a means of focusing the planning process, a means of comparing the long term effects of alternative plans, a means of opening the planning process and revealing the paths by which a solution is obtained, a base of knowledge and a focus for negotiation, a means of improving education and communication between all interested parties, and a means of improving decisionmaking through all of the above.

In evaluating FORPLAN as an economic tool, they identify several characteristics of an "ideal forest planning model" that also suggest research priorities. They suggest that the ideal should: be capable of maximizing net social welfare, consider the long run, distill all that is known about markets and seek an efficient allocation of factors of production to meet demands for goods and services from the forest, and easily make (analyze) tradeoffs between different forest resources (reflecting joint production).

In pulling the above observations together, Beuter and Iverson note the important tradeoff between technical capability of a system such as FORPLAN and complexity that makes understanding difficult. They suggest that developments which improve technical capability without resulting in "total unintelligibility" from some perspectives would be the best developments of all.

Beuter and Iverson also discuss the linkages between FORPLAN applications and: the RPA Program and the budgeting process, forest operations, and the outside world. Regarding the RPA Program and the national budgeting process, they conclude that insufficient linkages exist and that a fundamental inconsistency exists in that the budgeting process is functional (dealing with individual line items) while forest planning is oriented towards a more integrated analysis of jointly produced forest outputs. Regarding forest operations, they conclude that "what appears optimum for the forest may not be optimum for a watershed." They also state that the "link between operational feasibility and forest plans is tenuous..." Perhaps most strongly they conclude that "It is debatable whether it [FORPLAN] should be used for large-scale, forest-level planning...Version 2 may be best suited to site-specific project analysis..." These observations suggest a many-leveled optimization problem that is interactive from the national level down to the project level where omission of detail is unacceptable as is lack of central coordination. The implied research and development problems are substantial. Regarding the outside world, they observe that

"there has been little effort to develop national forest plans with sensitivity for the management of surrounding lands..." They cite Johnson and Greber (1986) in Oregon as an example of a more complete view. Again, the research and development implications of such a problem are quite challenging.

In summarizing their economic evaluation of FORPLAN, Beuter and Iverson note that the way such a model is used is possibly more pivotal than the raw capabilities of the model itself. And, they conclude that the role of FORPLAN in the planning process must be clarified. In their final remark, however, they ask, "If not FORPLAN, what?" Perhaps this indicates the first research need in this area--what are (if any) the alternatives to a large scale linear programming analysis of the forest resource allocation problem? Whether the most fruitful direction is further development of linear programming approaches or some fundamentally different approach, Beuter and Iverson provide the pragmatic guidelines outlined above.

Hof (1987) discusses the Beuter and Iverson paper and expands upon it in two areas: further evaluation of linear programming models in forest planning and linkages with higher levels of planning. Hof discusses four shortcomings of these linear programs.

First, he discusses the distinction between an economically defined production function and the activity analysis implied by a linear program. In terms of research needs and priorities, he concludes that a linear program will most closely emulate the ideal production function if essentially all technically feasible options (activities) are accounted for in the model. Thus, methods for developing these options require research and development.

Second, he discusses the importance and the difficulty of accounting for the spatial layout of management options in linear programs. He concludes that this is a most critical and intractable problem facing forest planning analysts.

Third, Hof questions the need for detailed acre-by-acre land allocations as a result of forest planning analyses. This suggests research oriented towards possible analysis techniques that provide decision rules or guidelines (as in some control theory and dynamic programming problem formulations) rather than specific numeric solutions.

Fourth, Hof discusses the problem of discontinuities in forest resource allocation problems and the limitations of linear programs in dealing with such discontinuities. He suggests research into the area of Catastrophe Theory to address these difficult problems. He suggests that many of the limitations of linear programming attributed to ignoring risk and uncertainty may actually be problems of ignoring discontinuities.

In terms of linkages to higher levels of planning, Hof concurs that such a linkage is clearly needed, and discusses options for achieving it technically. The first option is currently being developed (Hof and Baltic 1988, Hof and Pickens 1987), and involves using the FORPLAN solutions as choice variables in higher level planning models. The second option involves an iterative approach along the lines of Kornai and Liptak (1965). Both approaches are in need of further research and development. Hof also concurs with the fundamental difference in the functional perspective of the budgeting process and the integrated perspective of forest planning. Resolution of this difference is indicated to be more institutional than researchable.

Binkley (1987) identifies six "costs" of utilizing FORPLAN in forest planning: "analysis costs" (the direct costs of developing the system and building the individual forest models), "institutional costs" (potentially adverse effects on the agency from some people being excluded from the highly technical planning analysis, personnel changes, etc.), "increased centralization" (the loss of local flexibility from adopting a standardized planning system), "increased ignorance?" (the possible loss of information or understanding resulting from mathematical representations and models), "planning in a vacuum" (the losses from focusing on individual national forests without consideration of adjacent lands), and "implementation" (the difficulties of actually implementing the plans, including the problem of actual budgets not meeting plan budgets).

Binkley also discusses the "benefits" of the FORPLAN system and concludes that FORPLAN is "partially" effective in determining economically efficient solutions. He points out that reconciliation of political discord was an overriding objective of the new planning procedures. He also states that if simulation is the objective, then FORPLAN, as a linear program, may be "a poor analytical approach, and the principal benefit of linear programming--identification of economically efficient plans--is lost."

In terms of research areas to address the points summarized above, Binkley suggests the following:

1. Analysis of the analytical process itself. What were the costs and benefits of the first round of planning? How did actions change in response to land management planning?

2. Institutional factors. How did the Forest Service change in response to FORPLAN? What kinds of information were systematically ignored because of the modeling efforts? How can this information be brought back into the planning process? What are the limits of procedural rationality in national forest planning? How much technical information can be transmitted via the political system?

3. Large-scale modeling systems. Beuter and Iverson usefully distinguish model efficacy from model efficiency, pointing out that the first implementation of any system is not likely to be very efficient. But now it is time to turn to questions of efficiency. Can the recent advances in solution algorithms for linear programs--Karmarkar's algorithm, gradient projection techniques,...--be usefully exploited in the kinds of problems which arise in land management planning? Are there fast heuristics to take advantage of any special model structures typical of FORPLAN problems?

The Ecological Evaluation

The Problem

Shugart and Gilbert (1987) used 10 ecological facets to appraise the utility of FORPLAN in quantifying ecological processes:

1. non-linearities in ecological relationships,
2. variations in ecological time scales,
3. multiple resource interactions,
4. spatial dimension,
5. variation and error in model coefficients,
6. uncertainty in ecological processes,
7. succession and mortality,
8. dynamic versus static representations of ecological processes,
9. vegetative structure,
10. delineation of land units for analysis.

While Shugart and Gilbert (1987) describe the difficulty that one has in using FORPLAN to quantify these ecological facets, the end result is that analysts found ways to quantify these facets using FORPLAN. The problem was not all facets could be addressed at one time or in one model.

For every facet, Shugart and Gilbert (1987) give an example on how it was handled or how it could possibly be handled within FORPLAN. While the details vary for each particular facet, the approaches could be generally described as discretizing the ecological process and associating the ecological process with a fixed size of land. For example, mobile animal species are transformed into "fixed" resources by enlarging the land unit analyzed in FORPLAN or by linking the animal response with a zone (combination of land units).

Issues Related to Ecology

The struggles in trying to incorporate ecological processes into FORPLAN brought up issues related to the objectives of the FORPLAN model. In every attempt to quantify ecological processes in FORPLAN, model size, or duration of model run (and consequently model interpretation) becomes the real problem. As a result of this need to restrict model size, the "dilemma is deciding how much detail should be carried in the forest planning analysis tool and how much should be handled in separate steps" (Shugart and Gilbert 1987). Shugart and Gilbert (1987) emphasize that "some of the advantages such as reduced FORPLAN model complexity are achieved at the expense of increased analysis before FORPLAN."

Resolving this dilemma requires a definitive answer to the question "What is the objective of the FORPLAN modeling analysis?" Must all resources must be in a *single* decision analysis tool? Shugart and Gilbert (1987) admit that one might argue that the Forest Service should not be trying to do such comprehensive planning involving multiple stands and multiple ecosystems forest-wide, but the NFMA requires a *single plan*. Joyce (1987) suggests that the NFMA requires a single plan, not necessarily a single planning analysis tool, to accomplish comprehensive planning forest-wide. Clearly a closer examination of the modeling objectives is required.

Research Direction

If, as Shugart and Gilbert suggest, "the objective (of the modeling analysis) is to provide information which allows the exploration of resource production potentials using ecologically sound management," then their proposed modeling framework (fig. 1) increases the number and type of analytical tools that could provide information on multiple resource manage-

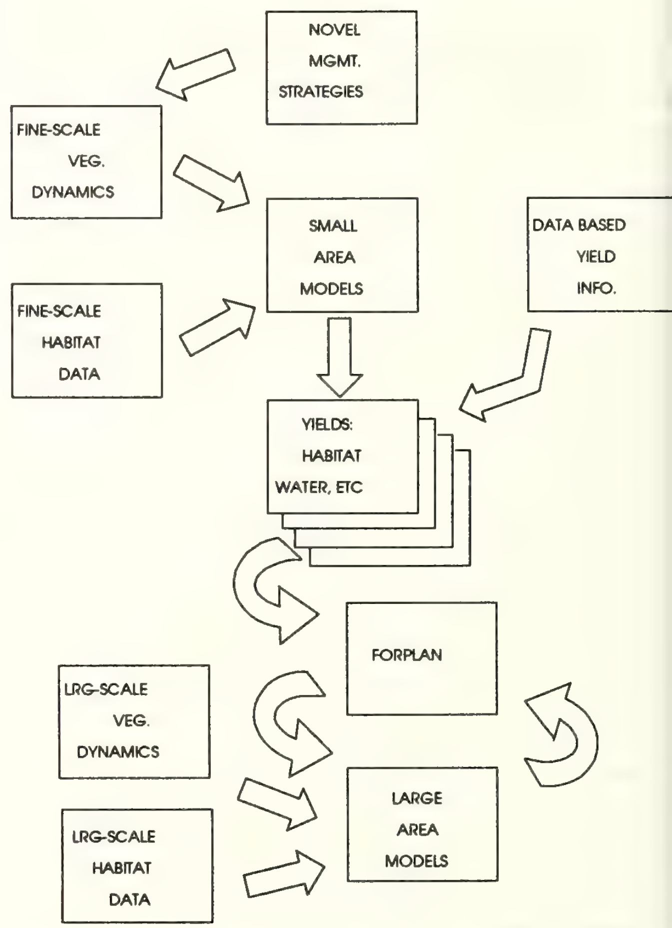

Figure 1.--Example information flows for large- and small-scal simulation as posr- and preprocessors to FORPLAN Large-scale models also could be used as preprocessors if appropriate.

ment. This approach as well as that of Joyce (1987) and Milne (1987) recognizes that: (1) resource production analyses need to be quantitatively linked in the planning process but not necessarily in one model, (2) resource interactions occur within different spatial scales, (3) resource interactions occur within different time scales, and (4) there is a need to incorporate the information between spatial and temporal scales in planning.

Shugart and Gilbert point out that "ecological sciences do not have a tradition of using linear programming to any great degree when compared with the well-developed traditions of statistical applications and differential equation models." Thus, the ecological sciences had little to offer in terms of guidance to analysts looking to capture ecological processes using the linear programming modeling approach. Shugart and Gilbert's proposed modeling framework (fig. 1) combines simulation approaches commonly used in ecological sciences with LP models to utilize the appropriate strengths at appropriate places in the exploration of resource production potentials. This proposed approach builds on ideas such as the featured-species plan (Zeedyck and Hazel 1974) and the area-diversity plan (Evans 1974), but adds the concept that changes in the landscape are important to consider in evaluating management activities. Milne (1987) stresses this later point further and describes a number of modeling approaches that might be used to quantify the landscape dynamics under different management strategies.

The FORPLAN model in this hierarchy becomes a land allocation and activity scheduling model where the inputs have been derived from the smaller scale models and the outputs have been examined in the larger scale models. Shugart and Gilbert (1987) stress that the advantages of reduced FORPLAN models are that they are simpler, less expensive to solve, and solutions are easier to check for reasonableness and to disaggregate to the ground. But, they suggest that "perhaps the biggest payoff, is the enhanced ability to comprehend and explain the solutions to management and the public." While FORPLAN has been reduced in this hierarchy, the number of pre- and post-models has expanded, and Shugart and Gilbert conclude that "it is also necessary for ecologists and scientists working with resource managers to explain the significant production functions necessary to make management decisions."

This last point is the most critical in terms of quantifying ecological processes and represents the greatest challenge to ecologists working in this area of research. Is it possible to standardize these production functions? Shugart and Gilbert proposed the key elements that need to be considered in developing an ecosystem/landscape management plan for regional species diversity. While developed for animal species, this approach could be expanded to other resources as well. The key elements are:

1. The ability to associate individual resource output with the features that make up a landscape.
2. The ability to predict the changes in the character of the landscape.
3. The ability to quantify the way species will respond to a dynamically changing landscape. This understanding should be both species-centered (how the dynamics of the ecosystem might effect a particular species of interest) and ecosystem-centered (how the success or failure of a given species might effect other components of the ecosystem).

These concerns can be used to define the research needed to further ecological modeling in forest planning.

1. Can individual resource outputs be quantitatively associated with features that make up the landscape, features that can be manipulated to manage the individual resource output? If yes, then both model building and management may be possible; if no, then perhaps basic research is needed to determine what ecological processes are involved.
2. Can changes in the landscape be predicted? Numerous techniques have been developed to predict changes in the landscape. Milne (1987) described a number of new techniques such as Bayesian models to determine the most likely wildlife habitat within the landscape. The problem here seems to be reliable data and an understanding of the differences across ecosystems.
3. And finally, is the scale of the land unit appropriate for analysis in the FORPLAN model? Shugart and Gilbert (1987) suggest that if the species habitat relations are the same scale as in the simulation model, then the dynamic changes of population as a function of change landscape can be simulated. This would be possible over the observed range for the species and landscape interactions. Thus, for previously observed management manipulations, the response of the species to the landscape could be quantified and used to address management needs.

What Shugart and Gilbert (1987) proposed is in many ways a more formally stated structure of what has/is going on in forest planning analyses. This structure does require additional models which would require additional modeling expertise and data. And while it looks complicated, it is no more complicated than many of the existing modeling structures associated with FORPLAN (Stage et al. 1986). One does have to ask the question as to whether the production information is available. For some resource analysts, not only is the answer to that question no, but also, they feel that we are misleading ourselves to think that the response of ecological systems can be quantified for all possible disturbances. Here again, the objectives of the planning process and the role that quantitative models play in that process need to be defined. Shugart and Gilbert present a framework in which the same model structure is used to examine ecosystem behavior under all possible disturbances. For analysts such as Walters (1986), the appropriate direction for resource management models is an adaptive learning ap-

proach in which an attempt is made to incorporate the dynamics of uncertainty in resource outputs, rather than attempting to describe the average behavior of the production system. This approach addresses two major problem areas, data quality and uncertainty, and merits further study as forest and rangelands become more intensively used and managed.

The Operations Research Evaluation

Bare and Field (1986) begin by determining what an operations research (OR) perspective is. They note that it is a systems approach to problem solving and decisionmaking and that OR practitioners will tend to attack normative or descriptive problems of the widest conceivable scope (Pollack 1986). The OR practitioners presume that a "rational-comprehensive" approach (Lindbloom 1959) will lead to an acceptable solution to any given problem. Bare and Field suggest that the last few years of forest planning raise doubts about the validity of this last assumption.

Bare and Field then turn their attention to an evaluation of the FORPLAN system itself. They begin by examining the mathematical basis of FORPLAN, including its inherent assumptions and their implications for decisionmaking. They also discuss possible alternatives to FORPLAN and recommend an approach to dealing with the next round of planning.

Bare and Field discuss five assumptions/limitations of LP: linearity, additivity, divisibility, certainty, and single criterion of optimality. They point out that linearity itself can be overcome with careful model formulation. Additivity and divisibility, however, are more difficult to deal with. Additivity implies that there can be no interactions between decision variables. Spatial concerns are a good example of how this assumption breaks down in a forest planning application. The divisibility assumption relates to the continuous nature of the decision variables. Unfortunately, most forest planning problems are mixed integer problems where some decision variables are continuous while others can assume only integer values. Examples of the latter type of decision variable include numbers of campgrounds, animals, etc., and timing choices for aggregate emphasis or coordinated allocation choices. Bare and Field suggest that careful formulation and solution interpretation may at least partially resolve these problems. The spatial problem has been identified earlier in this paper as a major research concern. The solution of large-scale mixed integer programming problems is also a significant difficulty, because no solution algorithm equivalent to the simplex method is available. While research into this type of problem lies outside the normal scope of forestry research, the advantages of development of improved methods for solution of such problems cannot be overestimated if the agency is to continue utilizing this modeling approach. Unfortunately, there seem to be minimal prospects for significant developments in this area with the possible exception of improved computing power using existing solution techniques.

The problems arising from the deterministic nature of LP models have been pointed out earlier in this paper. Bare and Field observe that the incorporation of probabilistic components in the already large FORPLAN models would lead to models that may be unsolvable given current state of the art solution techniques and computing capabilities. They also express the concern that a single criterion of optimality implies that there is a single decisionmaker. Sensitivity analysis is suggested as one approach to dealing with the problem of uncertainty while multi-criterion optimization techniques (Cohen and Marks 1975, Steuer 1986) are alternatives that address the single-criterion problem. Investigation into how to apply these techniques to forest planning applications is suggested. Bare and Field conclude their discussion by pointing out that while LP's limitations are significant, there exists no other modeling technique without similar limitations. The greatest danger, in their opinion, is that users of any modeling technique may not understand its limitations and think it functions better than it really does.

Bare and Field next turn their attention to the question of how well FORPLAN as an LP works. They conclude that the most serious problems--model understandability, analysis costs, and lack of resources to conduct sensitivity analyses--all arise from the formulation of models that are too large. While some of these problems have been addressed in part (Kent et al. 1987) much remains to be done.

The question of whether or not FORPLAN as a model is the right technique and is correctly used in forest planning applications, is addressed next. In answering this question, they focus on two closely related points:

1. the complexity of both the FORPLAN system and the models generated with it can allow for data errors and hidden assumptions to go undetected, and
2. problems that arise from the violation of LP's assumptions.

The second point and its implications have been discussed above. An important consequence of the first point is the fact that results can be obtained that are at least hard to interpret or explain and in fact can be misleading. Bare and Field conclude that many of these problems arise from the perceived need to include everything in one giant LP model following the rational-comprehensive philosophy. They recommend that the planning process be examined and suggest that a multi-stage approach (see also Mitchell 1986) might be more logical and understandable.

Attention is then turned to a third question--are the results obtained from FORPLAN models useful for forest planning? On the positive side they point out that FORPLAN has been useful as an accounting tool; that it has in some cases provided insights leading to "novel and defensible recommendations for National Forest Management;" that benchmark analysis also facilitated the development of insights and served to partially fill the gap left by incomplete sensitivity analyses; and that the

"future benefits to natural resource management" obtained from experiences with this first round of planning may be substantial. On the negative side they suggest that inadequate sensitivity analysis was conducted because "the models were generally too large, the time too short, the computing budget too small, and the analytical skills too limited." They also express the concern that there was "no clear understanding of the relationship between analysis and decisionmaking." A closely related problem in their opinion was that "failure to do real analysis or failure to recognize the distinction between insights and answers probably led to many unsupportable decisions based on invalid FORPLAN results."

Many of these problems, such as the need for more training, etc., are institutional in nature. However, the root of some seems, once again, to be large, expensive models which result from what might be viewed as an "all the eggs in one basket" approach suggested by rational comprehensive planning, and this does suggest research priorities as has already been pointed out.

Bare and Field next address the dual questions of why is FORPLAN an LP and what were the alternatives in 1979? We will not consider this discussion in detail except to observe that they conclude that "Forest Service analysts were justified in selecting LP as their prime 'mathematical apparatus' to drive the forest planning." They go on to qualify this by stating that in their opinion, while this decision was sound when one reviewed the planning tools that were available:

> "The major flow rested with the decision and (yes) the desire to satisfy the need for comprehensive analysis by building and solving a single, large scale LP model with thousands of rows and tens of thousand of columns. Apparently, insufficient thought was given to two fundamental questions: (1) Was the model to be used to guide strategic, tactical or operational planning? and (2) How relevant would model results be to on-the-ground managers and how easy would it be to explain model outputs?"

Bare and Field conclude their paper by suggesting alternatives to LP and FORPLAN and by outlining a procedure that the agency might follow in order to prepare for the next round of forest planning. We will discuss the two in reverse order to emphasize the point that broader questions pertaining to the planning process and the role of analysis must be answered before attention can be turned to the choice of analysis tools and procedures.

Bare and Field suggest the following 4-step procedure:

1. Evaluate the accomplishments/failures in planning
   a) Consider expected futures for the agency
   b) Examine the use and success of planning in other organizations.
2. Propose a new framework for Forest Service planning
   a) Recognize the changing philosophies in planning
   b) Recognize that planning is the continuous technique of adapting the organization to its environment
   c) Make every effort to integrate planning with management
   d) Do not let planning tools drive the development of the framework
   e) Recognize the rapidly changing computer technology
3. Specify the analytical support that will be needed to implement planning within the framework
   a) Include the level of administrative support that will be needed including authorizations for hardware, software, maintenance, development of analytical skills of users, and managerial time to link closely with planners and analysts.
4. Develop the necessary planning support system.

A number of both institutional and research priorities are clearly suggested.

Bare and Field also suggest a number of alternatives to FORPLAN in doing planning analysis. They make the point that all of these will most likely be more effective if the hierarchical nature of planning is recognized and separate models are utilized at each level. Among the mathematical programming approaches suggested are LP model reduction techniques (Navon et al. 1986), decomposition (Hoganson and Rose 1984), and multiple criterion optimization (Allen 1986, Bare and Mendoza 1987). Approaches that combine simulation and optimization (Hoganson and Rose 1984, Holling et al. 1986) may prove useful. Finally, they note studies that utilized LP (Hay and Dahl 1984, Hof and Pickens 1987, Weintraub et al. 1986) where the hierarchical nature of planning was recognized and large overly complex models were avoided.

We now turn our attention to the two discussion papers (Dykstra 1987, Navon 1987). Dykstra indicates that, for the most part, he agrees with the technical aspects of the Bare and Field evaluation. He does identify three concerns that need further consideration: data errors, the definition of analysis areas, and hierarchical or multi-level planning.

He distinguishes data entry errors from the more serious errors of measurement and classification. Measurement errors are identified as an especially serious problem for nontimber resources. In many cases, appropriate measurement procedures have not been defined for these resources. This can result in assessments with large measurement errors being used in FORPLAN models which in turn results in flawed FORPLAN analyses. Dykstra points out that this would be a problem regardless of the analysis approach utilized.

Clearly, additional research is needed in this area. It is to be hoped that the results of the first round of planning will be used to help identify the most critical data needs and thus aid in setting research priorities.

Dykstra goes on to suggest that data classification errors, unlike measurement errors, may result from FORPLAN analysis itself. As an example of this, he notes that different forest planning staffs have chosen different approaches and assumptions for defining analysis areas. In particular, some forests use contiguous nonhomogeneous analysis areas while others use noncontiguous homogeneous (traditional) analysis areas. He concludes that FORPLAN results, especially present net value calculations, can be significantly influenced by this choice. The question is which, if either, method of definition reflects how the forest is actually managed? This question needs resolution because, if an incorrect method is chosen, FORPLAN (or any other planning tools) results may be flawed.

Dykstra makes another observation concerning analysis areas. That is, different resources may require different definitions of analysis areas. As an example, wildlife do not necessarily concern themselves with the vegetative boundaries that have been one of the traditional parameters considered in analysis area definition. He suggests that to properly consider sets of overlapping analysis areas will require the use of a geographic information or similar system.

Dykstra's last concern relates to the question of hierarchical planning. He agrees with Bare and Field's conclusions but feels that their recommendations (as strong as they are) don't go for enough. He proposes a three level planning system with strategic planning (allocation) being conducted at the national level, tactical planning (scheduling) being conducted at the forest level, and operational planning (implementation) being conducted at the district level. The level and type of detail should vary as appropriate, with each level. For example, strategic planning does not require the type of detail needed to manage a forest while operational planning should be site specific and should have spatial integrity. He does not, however, specify any particular tools or analysis procedures that might be utilized. He does indicate that the multilevel optimization work of Hof and Pickens (1987) is an example of how this approach might be implemented.

Navon (1987) in the other discussion paper, takes a somewhat different approach to his evaluation, although he comes to many of the same conclusions. He begins by noting that, with a few minor exceptions, he is in agreement with Bare and Field's analysis. He then proposes a framework for evaluating computerized systems for planning. This framework addresses three sets of criteria:

1. is the system sound, i.e., is it free of logical and programming errors,
2. is it operational, i.e., can it be or has it been used correctly and cost-effectively in planning, and
3. is it relevant, i.e., does it or can it meet institutional requirements and information needs?

This framework is used to extend Bare and Field's evaluation of FORPLAN. Much of his evaluation addresses topics specific to the computer software and its documentation. These will not be discussed since, while important, they are not research-related. With regard to FORPLAN and how it has been used, Navon raises many of the same concerns as do Bare and Field. These include problems with model size and complexity, model cost, difficulty in conducting sensitivity analyses, and problems arising from uncertainty.

In some areas, he focuses on concerns beyond those which were addressed by Bare and Field. He is particularly concerned about the implications of the assumptions of LP (a concern that he feels is all the more serious because of the size of FORPLAN models). He suggests that these implications should be evaluated to establish whether an acceptable level of realism can be reached using LP. He is also concerned about the implications of poor quality data on FORPLAN results. Inputs and outputs should not be included in FORPLAN models if reliable data on them are not available. He, like Bare and Field, feels that an evaluation of all aspects of the first round of planning needs to be conducted.

Despite these problems, Navon arrived at somewhat different conclusions about FORPLAN. He feels that the system has addressed Forest Service institutional requirements but, because of the problems mentioned above there are questions about the adequacy and reliability of the information provided. He does feel however that there are no attractive alternatives to FORPLAN available. Rather, the solution to the dilemma is to restructure the way in which FORPLAN is used.

Towards this end, he recommends, like Bare and Field and Dykstra that comprehensive site specific planning be replaced with a hierarchical approach. He goes on to outline an approach which may alleviate many of the problems outlined above. His approach differs from Dykstra's in two important ways. One, it would involve the use of FORPLAN as the central analysis tool. While Dykstra did not preclude the use of FORPLAN, he did leave the question of analysis procedures open. Secondly, while both system contain three steps, in Navon's system, all three would take place at the forest and district level, while Dykstra's proposal included one planning step at the national level. Of course, there is nothing to preclude the addition of a fourth step to Navon's system that would relate to National Level planning.

The implications for research arising from Navon's recommendations are much the same as those discussed in the context of the previous papers and, therefore, they will not be repeated.

CONCLUSIONS

Perhaps the most interesting conclusion to draw from this review is the consistency with which certain research problems were identified. This is especially interesting when the diversity of participants in the two meetings is considered. We group these problems into one of two categories, basic and applied.

and then briefly identify some of the more important ones in each category. Important problems in the first category include:

1. A more complete characterization of the agency's overall planning process needs to be developed.

2. Once item 1 is completed, the role of forest planning, and the role of analysis can be more clearly defined.

3. With the planning process and the role of forest planning characterized, attention can be turned to an identification of planning strategies (i.e., rational comprehensive vs. hierarchical) and the role of analysis in planning.

4. The choice of analysis tools must then be considered and new systems must be developed or existing ones modified as appropriate. Necessary linkages between systems must also be identified and developed. This work must take into consideration the need to better incorporate nontimber resources, spatial concerns, and uncertainty in planning analysis. Throughout all of these investigations, the need to make planning and analysis understandable to interested parties both in and outside the agency must be kept in mind. Necessary linkages between different levels of planning must be developed and at all times the underlying goal of improving management and decisionmaking through planning must be kept in mind.

Among the more important applied problems are:

1. Critical data needs for planning and analysis must be identified and satisfied.

2. Our understanding both of how to implement plans and utilize the results of implementation to facilitate the next round of planning must be improved.

3. A better understanding of the implications of budget levels on planning must be developed.

While this paper has focused on problems with the first round of planning, we must point out that much has been accomplished. It is also clear that the problems surfaced during the two meetings are difficult and will be challenging to address. As is often the case, the difficult problems are the last to be resolved.

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Applications of Markovian Decision Models in Forest Management

Joseph Buongiorno and Ismail Kaya[1]

Abstract.--Markovian decision models represent a practical approach to decision making under risk in forest management. Very complex stochastic systems models can be reduced to simple transition probability matrices that constitute the core of a Markovian model. Optimization techniques can then be used to find the best management strategy. The method will be illustrated with an application to selective cutting in northern hardwoods. The results suggest that Markovian management guides could increase returns considerably, compared with either traditional guides or deterministic models.

Risk is an inescapable element of decision making in forestry. Risk arises within the forest itself, and in its environment. Our knowledge of the biological growth of forest stands is still imperfect. We can only tell very roughly how trees will grow, and even if we could tell, that growth will always be subject to the vagaries of the weather. Unfortunately, chaos theorist have demonstrated that accurate long-term weather forecasting is impossible (Grebogi et al. 1987). Even worse is our inability to forecast the environmental variables that bear upon forest decision making. Take as a simple example the case of timber prices. Forecasting them, whether in the short or long term, seems a very difficult endeavor. One that is most likely as unattainable as weather forecasting.

The consequences of this situation seem inevitable. Risk should be taken explicitly into account in formulating forest management policies. This is a situation that has been recognized very early by some pioneer of forest modeling. For example, Gould and O'Reagan (1965) in their forest simulator used a stochastic function to simulate random fires. It is easy to show that when such catastrophes can wipe out forests, the best decisions (for example the choice of a rotation) are quite different from those provided by deterministic calculations (Buongiorno and Gilless 1987, chapter 15).

Nevertheless, few studies have attempted to devise optimum forest management policies in the case of complex systems involving several decision variables. One early exception was Hool (1966), who was the first to suggest a Markovian decision framework. He applied it to even-aged plantations, to maximize the volume produced within a finite time horizon. Hool's work was followed by that of Lembersky and Johnson (1975) who used the same principles to maximize the soil expectation value of Douglas-fir plantations in the Pacific Northwest. Lembersky (1976) modified the model to maximize the annual volume produced, also with a infinite horizon.

Few Markovian decision models, in forestry or other fields, seem to have been implemented (White 1985). This is surprising. Markovian decision models are conceptually simple, they are easy to solve, and if the state variables are well defined, the results are easy to apply. We shall try to illustrate this simplicity and power with a recent application of the method to uneven-aged management (Kaya and Buongiorno 1987).

[1]*Department of Forestry University of Wisconsin Madison, WI 53706.*

Basic Concepts

The core of a Markovian decision model is a matrix of probabilities p(j|i,k) giving the probability that the system of interest (let us say a stand of trees) ends in state j after a certain time interval, given that it starts in state i and that the decision k is made.

This probability depends only on the starting state and on the decision, regardless of the past history of the system. This Markovian property is not really a serious limitation because the states can always be defined so that the property is very closely verified.

Associated with the transition probability matrix is a return matrix $r_{i,k}$ that gives the immediate return obtained from the system in state i when decision k is made.

The objective function may vary. Throughout the remainder of this paper we shall assume that the manager's objective is to maximize the expected total discounted value of the returns, over an infinite horizon.

The problem then is to define the optimum policy, that is the best way to make every decision. It has been shown (e.g., Howard 1960) that among all possible policies there is at least one stationary policy that is optimal. A stationary policy assigns one single decision to each possible state.

In the following sections we shall discuss the choice of system states, the computation of transition probabilities, and the determination of an optimal solution in the case of uneven-aged forest management.

Choice of System States

Development of a successful Markovian decision model requires careful definition of the system states. In the case of uneven-aged stands, the definition of a state must be simple so that it is easily implemented in the field. Nevertheless, it must allow for a wide array of management regimes.

In our system each state is defined by a combination of a stand state and of a market state. The market state is defined simply by the level of product prices, which may be high, medium, or low. Stand states are defined by the amount of basal area in three product classes: pole timber, small sawtimber, and large sawtimber. For each product class we defined five levels of basal area, from "very low" (0 to 10 square feet of basal area) to "very high" (75 square feet of basal area or more).

Computation of Transition Probabilities

One of the most difficult parts in building Markovian decision models is the choice of transition probabilities. Recall that this is the probability that the system moves from one state to another, when a particular decision is made.

In the case of uneven-aged management, a decision consists simply of doing nothing, or of cutting the stand from a particular state to another, by reducing the basal area in one or more of the three product classes. Then, each transition probability is the product of the stand transition probability (probability that it moves from one state to another) by the probability of a particular product price level. This is so because prices are independent of stand states, and in efficient markets, prices are uncorrelated over time (if they are not, this can be easily taken into account).

The main task, then, is to determine the transition probabilities between stand states. This is usually difficult to do from direct observations (for example from permanent sample plots). There are simply not enough observations to cover all the stand states that may occur in actual management.

A practical alternative is to use stochastic simulation. In the case of uneven-aged management, several stand models exist that give not only the expected value of stand growth, but also some measure of the variability around that expected value. In the best cases, not only are the standard errors available, but also the variance-covariance matrix of the residuals (Michie 1981). Then, for each time interval, one can compute the deterministic component of growth, and add a stochastic part by sampling from the multivariate distribution that describes best the residuals of the model.

This kind of simulation can be used effectively to count the number of passages from a stand state to another, when a wide variety of harvests are applied to the stand (random harvests will do, the idea being to make sure that during a simulation the stand visits as many possible states as possible). Then, a summary count of the relative frequencies of passage from one state to another gives the desired probabilities. Those states that occur very rarely can be omitted, thus reducing considerably the size of the problem.

This simulation technique is a practical way of "bringing the real world to the laboratory" (Holling et al. 1986). In effect, this procedure condenses the information contained in a possibly complex simulation model into a simple transition probability matrix to which powerful optimization methods can be brought upon to compute the best policy.

Determination of Returns and of Best Policy

In our system the basal area cut in each product class at decision time is the difference between the basal area before and after harvest. From this and other information on stand state and costs of harvesting, one can determine the value of the cut, that is the immediate return, when a particular combination of stand and price state is observed, and when a particular decision is made.

This transition probability matrix, together with the matrix of immediate returns provides all the information needed to compute the optimum policy. Several approaches are possible to do the computations. They include linear programming (d'Epenoux 1963), policy improvement algorithms (Howard 1960), and successive approximations (e.g., Ross 1970).

Successive approximations seems to be by far the best approach. It does not require the solution of a large system of simultaneous solutions at each iteration. Thus, quick solutions of very large problems are possible on a microcomputer, using successive approximations . Like policy improvement, but unlike linear programming, this method gives besides the optimal policy, the stand value (i.e., the discounted value of future returns when the best policy is followed) in function of the initial state. Best of all, successive approximations is conceptually straightforward. It consists in solving the following recursive equations:

$$V_i^{t+1} = \underset{k}{\underline{\max}} \, [r_{i,k} + d\Sigma_j p(j|i,k) V_j^t] \text{ for all } i$$

where V_i^t is the expected discounted value of returns from initial stand-market state i, managed optimally for t periods. The discount factor is d.

This equation says that the best decision at time t must maximize the sum of the immediate returns and of the dis-

counted value of the returns generated earlier by following the optimal policy.

The method of successive approximations consists of applying the above equations, starting from arbitrary values of V_i^0, say zero, and increasing t until V_i^t converges. The limit of V_i^t as t increases to infinity is the discounted value of the returns from the stand, given the initial condition i, when the optimum policy is followed. Thus it is the stand value, inclusive of initial growing stock and land.

Results and Implementation

The main results of a Markovian decision model can be summarized by a decision table. In our case that table gives the best decision (stand state after harvest) for each combination of stand and market state (price level). Because the optimal policy is stationary, that decision table is unique; in particular, it is independent of the initial stand state. Because state variables are easy to measure in the field, such a table represents a practical harvesting guide.

In contrast to the harvest policy, the stand value depends very much on the initial condition of the stand and of the market. As seen above, this stand value is a by-product of the method of successive approximations. This information can be extremely useful for forest valuation. It is also useful in comparing a Markovian cutting guide with others.

In the case of northern hardwoods management we found that stand values obtained by applying a Markovian cutting guide were much higher than those yielded by the traditional Lake States cutting guide. They were also generally superior to those obtained with a deterministic optimization model (the gain varies with the initial condition of the stand and market, see Kaya and Buongiorno 1988).

Within the framework of a Markovian model, the cutting cycle is a random variable; a stand is not necessarily cut every time it is examined. Similarly, the amount of timber cut, and the corresponding residual basal area, are random variables. They vary depending on the price level and on the state of the stand. Nevertheless, one can from the solution determine the expected cutting cycle, the expected value of the cut, and the expected residual area after the cut (Kaya and Buongiorno 1987). Thus, all the information available from classical harvesting guides can also be obtained from the solution of a Markovian decision model.

Conclusion

Markovian decision models should have great potential in forestry decision making. They represent a simple, yet general, way of recognizing elements of risk in the outcomes of decisions. From our experience in uneven-aged management, policies developed from Markovian decision models may be quite superior to those computed by deterministic models.

The core of Markovian decision models consists of a transition probability matrix that can be obtained by stochastic simulation. The simulator serves to "bring the real world to the laboratory" (Holling et al. 1986), and the simulation experiments are summarized compactly in the transition probability matrix. Then, efficient solution algorithms can be used to obtain the optimum policy. This seems a better way of finding a policy than exploring the response surface of a complex simulation model.

The resulting policy is stationary: to a state of the system, regardless of when it occurs, corresponds a single best decision. As such the policy is very simple to apply, as long as one takes good care to define system states that are easy to recognize in practice. The policy does not need to be recomputed frequently, only when significant changes have occurred in the distribution of price changes, or in the growth of stands.

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A Comparison Between Timber Harvest Projections for a Northwest Forest Solved Using Model II Linear Programs on a Micro and Mainframe Computer

Thomas A. Thomson[1]

Abstract.--This paper compares results between two Model II linear programs used for timber harvest analysis on an industrially managed forest in the Pacific Northwest. One model was run on an IBM PC and the other on an IBM mainframe. The mainframe model was the MUSYC model developed by the U.S. Forest Service. The micro computer model was written by the author for solving the given harvest analysis problem. The timber harvests projected were within a few percentage of each other, both on the base case run, and for numerous sensitivities. The mainframe model had the ability to provide a more detailed solution. The micro computer model provided a similar result, however, with no time share charges, and may be a more realistic representation of the timber harvest pattern to evolve on the ground. Model selection depends on the level of detail desired by the decision makers, and the personnel and computer resources available. It may also be a good strategy to build both models as was done in this case. The micro computer model was used often to perform low cost and fast turn around sensitivity analysis after it was established as a tool which provided accurate solutions.

All forest land owners make decisions regarding timber harvest rates over time. Much of forest management is related to this decision as desired harvest levels effect reforestation and stand management decisions. In the past such decisions were often based on volume or acre formulas. With the increased use of computers, these decisions have been analyzed using computers. Organizations such as the USDA Forest Service, a number of state agencies, and many large timber corporations now use large linear program models for assessing alternative harvest patterns (Davis and Johnson 1987). Small organizations may not have access to this computing power but typically may have access to micro computers. This paper presents comparisons between results gained from both a micro computer model and a mainframe model for a forest tract in excess of 100,000 acres.

[1]*Assistant Professor of Forest Management, University of Michigan, School of Natural Resources, Ann Arbor, MI 48109-1115.*

The mainframe timber harvest scheduling model used was the Multiple Use Sustained Yield Calculation (MUSYC) model developed for the U.S. Forest Service (Johnson and Jones 1979). This model consists of a matrix generator and a report writer which is run in conjunction with a linear program solving package. MUSYC builds the matrix, feeds this matrix into the linear program solver, and then interprets the linear program output giving both detailed and summary information. The micro computer model was constructed by the author using the LPX88 linear programming package from Eastern Software Products[2] (1985).

There was no deliberate plan to run both a micro and mainframe timber harvest model, rather it evolved as step in the

[2]*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of a service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.*

timber harvest planning process. An evaluation of sustainable timber harvests was being performed for all timberlands divisions within the company; the forest under study was one of the areas covered in this program. The company was using either MUSYC or FORPLAN (Johnson 1986) to do these analyses. The steps for doing the analysis were the standard ones of aggregation of stands into stand types, projecting the yield and value over time, and putting this information into a LP to maximize an objective while meeting a set of constraints.

The company's timber inventory was an in-place, type map inventory. Reinventory was an ongoing process so the years since last inventory for a given stand was variable. The records were maintained in a custom data base on a 16 bit minicomputer. Because of the slowness of this machine and the lack of appropriate software, the relevant inventory information was uploaded to the mainframe computer to stratify timber stands for aggregation into stand types. In excess of 2,000 timber stands were recognized in the forest inventory. Using the Statistical Analysis System[2] (SAS), the stands were stratified by age, species, site, and stocking. Five-year age classes were recognized, except that all stands over age 65 were merged to the oldest age class.

The four species grouping were Douglas-fir, Hemlock, Mixed, and Hardwoods. Stands with less than 60% of their growing stock in Douglas-fir, hemlock, or hardwoods were considered mixed stands. Site quality was initially divided into to four classes. If too few acres resulted after this stratification process, site classes were merged so that in most cases, only two classes were recognized: good sites and poorer sites. Stocking was also divided into four classes, but after further aggregation to meet minimum stand type acreage guidelines usually only two stocking classes remained. Aggregations containing less than 200 acres were further merged with the most similar existing stand type to create stand types of at least 200 acres.

The result of this stratification process was about 120 stand types which were to be used in creation of the decision variables of the models. For each stand, the number of acres, number of trees, and average diameter by species class, site index, and age was computed. Each stand type was projected over time in 5-year increments using a modified version of Arney's (1985) Stand Projection System[2] (SPS). The SPS modifications were in the log bucking and scaling routines. In addition, the model was modified to calculate the economic value of the stands. The projected timber yields, harvest costs, and harvest revenues were input into the Smart Data Manager[2] (Innovative Software 1986) to be available for reporting in various ways.

This process was completed before it was time to run the MUSYC model so the author decided to undertake a preliminary analysis of the sustainable harvest by building a small linear program. The construction of this small model was seen as a process that would help determine if there might be any hitches in the model construction of the MUSYC model. We wanted to be apprised of any problems while we still had time to solve them.

Construction of the Micro Computer Timber Harvest Model

The goal of constructing the micro computer model was to give a preliminary estimate of the sustainable harvest of the forest. The linear programming (LP) software program that we had, LPX88, is capable of solving a sparse matrix of about 500 rows and 1,500 columns. We were using a two-diskette drive, IBM PC for solving the matrix. We decided to keep the model small to minimize its construction and solutions time. To retain what we deemed the most important information, we decided to aggregate the results across species, site, and stocking, so all that remained were 10 timber types of the various ages, plus an additional three types for representing severely understocked stands. All regenerated stands were merged into a composite stand representing our best estimate of the average yields and values we expected regenerated stands to provide. We used the Smart Data Manager to implement the merging, thus the merging of stands was completed after the growth projection had been done. The timber yields in the micro model would thus be the same on average as the yields from the MUSYC model.

Each stand type (existing and regenerated) was allowed as a harvest candidate at age 45, 50, 55, and 60, except that all existing stands were allowed at least three future periods for harvest. Twenty, 5-year periods, or about two rotations, were used as the modelling time horizon. A series of decision variables that represented the harvest options for current and regenerated stands and the periodic harvest definitions made up the columns of the matrix. Constraint rows were the harvest definition rows, the Model II regeneration transfer rows, the acreage constraints, and the harvest flow constraints. Model size was about 100 columns by 85 rows. The objective function was to maximize the discounted timber harvest. As long as all timber volume had the same per unit value, then this would approximate the maximization of net present value which was the firm's objective. This was accomplished by simply putting the appropriate discount factor for each period into the objective function row of the harvest definition variables.

The linear program was solved and a series of sensitivities performed. The model took about 45 minutes to solve with the previously described computing system. I have subsequently solved the model on an IBM AT compatible computer (Zenith Z-241 series) with numeric data coprocessor and RAM disk in about 5 minutes. Initial harvest projections were for a non-declining harvest, and a modulated harvest flow that allowed a decrease of 1% per year (5% per period), or an increase of 2% per year. A 5% discount rate was used.

The non-declining solution showed a constant cut for eight periods at which time the currently managed young plantations provided a source of higher harvests. The modulated flow had a higher first period harvest which then declined at the maximum allowable rate for eight periods before beginning an increase which was followed by another decrease cycle. The discounted cut was about 3% lower for the non-declining harvest. Studying the decision variables demonstrated that the

model was generally choosing stands in order of their age, that is, oldest stands were cut first, then the next oldest, and so forth. After examination of the preliminary solution, several sensitivity tests were requested to evaluate the concerns of the forest managers.

Sensitivity runs investigated the effect of a higher discount rate (7%), the effect of lower yields on regenerated stands, the effect of a 10% lower growth rate, the effect of separating the two major operating units within the model (the opposite of an allowable cut effect), and the effect of a lower initial starting inventory on some stands for which there was a concern the inventory information was less reliable. The increase in the discount rate had no effect on the harvest flows. In other words, timber harvest constraints were more important than the discount rate. Likewise, lowering regenerated stand yields had no effect for the first 40 years of the model. It simply meant that future yields would be lower. A 10% decrease in the growth rates decreased the initial cut for non-declining yield by about 5%, and somewhat more for the modulated flow. Decreasing initial stand inventory on some stands decreased the initial harvest slightly. At this point, there was a sense that the harvest flow capabilities of the forest had been fairly well identified.

Construction of the MUSYC model

The next phase was the construction of the MUSYC model. The data base manager was used to print out files of timber yields, and harvest cost and revenue data. These files were then uploaded to the mainframe and merged into the MUSYC input file. All 120 stand types were listed individually. A single regenerated stand table, as used above, was also included in the MUSYC input.

After trouble shooting the MUSYC model it was then solved with the same harvest constraints used above. The objective was to maximize net present value, but in this case the harvest costs and revenues from each stand type were used to generate the NPV. Also, a higher discount rate was used. The resulting harvest flow, however, was within 3% of that projected by the micro model discussed above.

The nature of the MUSYC solutions, however, were much more specific, and also quite different. Whereas the micro model chose stands on the basis of their age, the MUSYC model went after value. It first harvested the Douglas-fir in the most valuable unit, then harvested the Douglas-fir in the other units, then the hemlock in the most valuable unit, then the hemlock in the other units, and finally hardwoods. This solution could be predicted for an optimization problem operating under a high discount rate. This solution, however, was not deemed operationally feasible.

The next stage in the MUSYC planning process was to determine ways to place constraints on the model to yield solutions that were deemed operationally feasible. Harvests could not be concentrated on one unit due to both log flow concerns at the mills, and watershed values of the forest. The mills were not interested in a continual shifting of species. Operationally it was also recognized that logging settings include some less desirable acres along with the good ones. A further problem was that the high discount rate caused the model to harvest extremely young stands for harvest, stands for which the trees were not of a large enough size for the profitable running of the wood products converting plants.

A set of additional constraints was added to the MUSYC model to recognize these operational realities. Limits were placed on the amount that could be harvest in any unit in each period. Limits were also placed on the species mix to ensure that changes in the mix were at an operationally feasible level. Poor quality timber stands were forced into the solution. Because piece size constraints were not a part of the MUSYC model construction, harvest age was constrained to be not less than 50 years to insure that minimum piece size requirements were met. The model was then resolved, with similar harvest flows resulting, but with different choices of stands to be harvested over time.

Some of the same sort of sensitivity results as had been done on the micro model were also done on the MUSYC model with essentially the same results. Additional sensitivities that could be run were sensitivities to an increase or decrease in timber prices. A 10% increase or decrease in timber prices had no effect on the solution (other than the reported NPV). We were also able to determine at which discount rate the model would choose to build growing stock rather than harvest as much as possible as fast as allowed.

The micro model was then amended to reflect any changes that could be placed into its structure. The biggest change was restricting timber harvests to stands 50 years or older. The micro model was then resolved and the results compared. Figure 1 shows the difference in harvest flow predicted by the two models when under a non-declining flow constraint. The solutions are within about 1% of each other. Figure 2 compares the results when harvest are allowed to decline up to 1% annually, but may double between periods. The solutions are within a couple of percent until the recent plantations and regenerated stands come on line, at which point they diverge.

Discussion

The results presented here have demonstrated that, at least for the forest shown here, the harvest flow results are essentially the same for the MUSYC model and the micro model. While this is only anecdotal evidence for a general claim, it may hold for many forests. Johnson and Tedder (1984) note that for straightforward problems, binary search will provide the same solution as a detailed linear program. In special cases, the large linear program solution can reveal insights not gained in binary search. Although this is a comparison of linear program to linear program, the MUSYC model certainly represented more detail and may for certain forest structures yield a fairly different result than could be obtained using a micro model.

For a manager trying decide which approach to use for determining appropriate harvest levels I offer the following insights:

1. There may be no choice. Smaller landowners may have neither the computing nor human resources needed to use something like the MUSYC model. Public land managers, or private managers operating in centrally controlled firms, may be administratively constrained to using such models. For the those not in one of the above categories, it probably makes sense to use the one which is easiest. As noted above, the initial steps in forest planning are the same, regardless of the modelling approach chosen. Those steps are stratifying the forest land into homogeneous timber classes and predicting yields and values. These projections over time must then be interfaced with the harvest analysis model. When the harvest analysis model is an LP, one constructs an LP that describes the growth and cutting options available on the forest.

The degree of effort required to build and analyze the results of either model depends on the background of the user. The MUSYC model has extensive documentation on how to prepare the input and use the model. Those not familiar with the model would have to invest a lot of time to learn its operation. The micro model, on the other hand, requires construction of the linear programming matrix and interpretation of the results. No summary information is presented on the output. For someone familiar with linear programming, it would probably be faster for him or her to set up, run, and interpret a micro model than to learn how to use the MUSYC model. For someone without the knowledge to set up a linear program model, use of a model such as MUSYC would probably be faster than learning about linear programming. Linear programming for use in timber harvest scheduling is now taught at most forestry schools, though usually only the top undergraduates gain a working knowledge

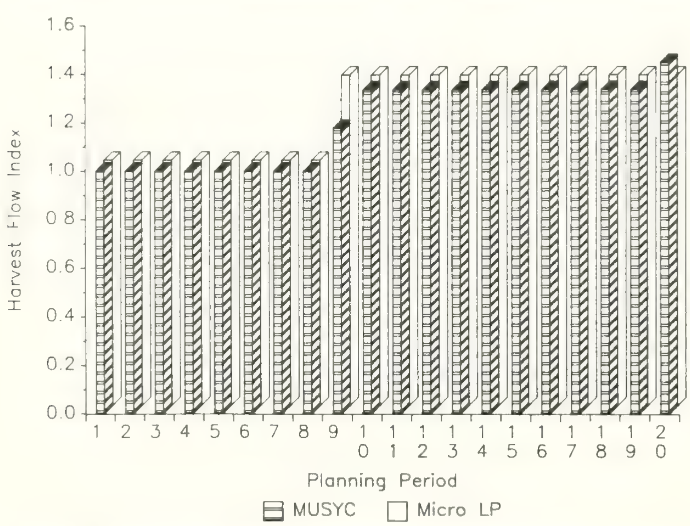

Figure 1.--The harvest flow projected by the MUSYC model and the micro model under non-declining harvest flow constraints.

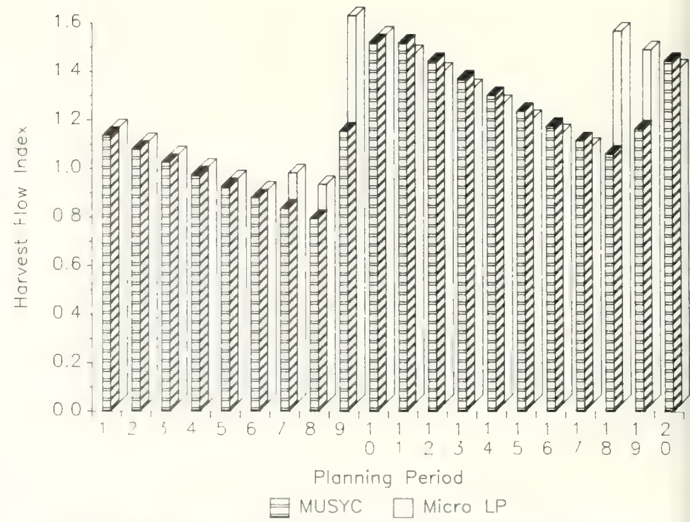

Figure 2.--The harvest flow projected by the MUSYC model and th micro model under modulating harvest flow constraints.

suitable for setting up their own linear programs. Graduat students studying forest management or quantitative analysi would gain the requisite modelling skills.

Time share computer charges are probably less importar than human resources cost in which ever solution is chosen. Th MUSYC modelling effort was probably charged $2,500 t $3,500 of time share charges. The human resources cost i setting and run the model was no doubt more costly tha computer time charges. The linear program software for th micro computer cost under $100, and added no further comput ing cost. MUSYC models were typically run at low priority ove night to keep their cost down. The micro model was often ru over lunch hour to not tie up the micro computer.

2. It depends on the amount of decentralization in decision making. For a firm that wants to centralize decision making and provide control over practices in various divisions, a large scale model with central expertise for constructing and running of the model can ensure greater consistency than if each division were to construct its own.

3. What is possible on the ground? The biggest problem with the initial runs of the MUSYC model is that the solution would not be implemented. Even if the solution could have been implemented, those doing the day to day management would manage a solution they were comfortable with. The MUSYC model provided more detail than could probably be executed on the ground. One could argue, of course, that the MUSYC model should have recognized fewer, or perhaps a different sort of, decision variables to provide a more realistic solution. The micro model provided a more general solution that proposed to cut in relationship to what is out there on average--something that in general is implemented. The MUSYC model showed a penchant for early

harvest of the more valuable Douglas-fir stands. Even if only the micro model had been run, however, there would still be the tendency by the managers to seek out the Douglas-fir stands due to their greater value.

4. There is some value to running both. By constructing both models, the division was able to determine what it thought reasonable, and the corporate headquarters was able to do quality assurance of the final result. The micro model was originally set up to provide a dry run through the system before constructing the MUSYC model. We felt that going through the process would alert us to any problems that needed to be solved before the large model was constructed. In addition, it was seen as a means to verify the integrity of the MUSYC model, as any deviation between the models would trigger an investigation of both.

5. The micro model was used extensively for low cost, fast turn around solutions to various sensitivity analyses that were requested from time to time. This meant that corporate expertise was not required and the MUSYC model did not have to be retrieved from magnetic tape. The validity of the solutions to the micro model had been established by comparison to the MUSYC results. For doing the sensitivity analyses it was easier to use a micro model than the MUSYC model.

6. The anecdotal evidence of similar results between models suggests that those with a stake in the outcome of timber harvest models, but not the resources to construct an equally detailed model, could build a micro model to test the validity of the model of concern. Environmental groups, for example, could construct a small model to satisfy themselves that the public modelling results are realistic. Industry groups could likewise build small models to investigate timber supply concerns.

7. A much bigger model could have been constructed on the micro computer. Because we used only one-fifteenth of the columns and one-fourth of the rows that the software allows we could have constructed a micro model that was more similar to the MUSYC model. We also could have paid much more attention to the timber economics within the model. We did not, however, see a need to do this.

8. The primary dispute on how to manage the forest could not be solved by either model. The real issue was, which harvest flow pattern was best? No model can build in the intricacies of market fluctuations. Managers want to know the capability of the forest to produce stumpage over time, to integrate this result with the vagaries of the market in choosing which timber stands will be harvested when.

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Integrating Short-Term Spatially Feasible Harvest Plans With Long-Term Harvest Schedules Using Monte-Carlo Integer Programming and Linear Programming

John Nelson, J. Douglas Brodie, and John Sessions[1]

Abstract.--A procedure for integrating spatially feasible area-based plans with long-term, strata-based plans is presented. Area-based plans are generated by Monte-Carlo integer programming, and subsequently used as coordinated allocation choices within FORPLAN. The integrated plans provide spatially feasible alternatives in the short-term, and also ensure that long-term volume and net revenue flows can be sustained.

Introduction

Problem Definition

Harvest scheduling problems can be broken into two broad categories. First, there is the long-range plan that looks ahead over several rotations (150+ years), and provides an estimate of what volumes should be cut from various stands within each decade. These plans do not necessarily provide a spatially feasible solution, since the stands are aggregated over vast areas, average costs and yields are used, and individual harvesting units are not specified.

These forest wide, long-range plans are usually solved by either binary search, shadow price search, or linear programming techniques. The advantages and disadvantages of these techniques are summarized by Davis and Johnson (1987) and also by Eldred (1987). Linear programming (LP) is the most flexible method because of its ability to maximize outputs under a variety of constraints. The model formulation is based on timber strata, and is therefore referred to as strata-based planning. FORPLAN (Johnson 1987) is a widely used LP model used for long-term planning.

The second category of harvest scheduling problems deals with determining a spatially feasible solution that covers a shorter planning horizon (1 to 5 decades). Based on the harvest levels generated in the long-range LP, individual harvest units and road projects are selected for a relatively smaller area in this type of a plan. Because the problem is formulated from specific harvest units, this type of planning is referred to as area-based planning. Since this approach requires integer solutions, these problems are usually solved with mixed-integer programming (MIP) techniques. The Integrated Resource Planning Model (Kirby et al. 1980) is a MIP model developed for area-based planning. Integer variables are needed for road links and harvest units to prevent them from splitting between time periods. Splitting can complicate adjacency restrictions, resulting in a situation where very small percentages of the unit are left for future periods (Moore and Nielson 1987).

Integer solutions greatly increase the computational burden of the problem, thus MIP techniques are not well suited to large planning problems. Another disadvantage of MIP is that the entire forest must be partitioned into specific harvest units complete with planned roads and logging systems. Not only is this an enormous engineering task, but it also assumes that current logging systems and technology will remain unchanged throughout the planning horizon.

Other approaches to solving area-based planning problems include simulation and random sampling techniques. The Project Area Scheduling System (PASS) developed by Tank (1985) for the USDA Forest Service is a simulation model designed for assessing area-based harvest scheduling problems. An important demand for this tool was the need to disaggregate FORPLAN solutions into a workable schedule of timber sales and road projects. Its major advantage is that it can quickly

[1] *The authors are, respectively, Graduate Research Assistant (on graduate study leave from the University of British Columbia), Professor of Forest Management, and Associate Professor of Forest Engineering, College of Forestry, Oregon State University.*

manipulate large volumes of data necessary to assess alternatives. The major disadvantage is that the analyst must provide the scheduling choices, and given the large number of possibilities, attempting to find optimal or near optimal solutions can be a difficult task (Jones et al. 1986). Tanke's work is a valuable contribution when compared to manual methods traditionally used to resolve harvest scheduling problems. When hundreds of variables and possibly thousands of alternatives are involved, arriving at just one or two feasible solutions is a major achievement.

Sessions (1987) has recently introduced a procedure in which random patterns of harvest units are generated, and then tested for adjacency constraints and harvest levels. While this procedure does not guarantee optimality, it is effective in quickly generating "good" alternatives. It is also an improvement over PASS in that the algorithm generates the harvesting schedule. Session's method uses a heuristic procedure to identify the "optimal" schedule and road network once feasible patterns of harvest units have been identified.

The situation can be summarized as follows. Strata-based planning is an efficient way to determine long-term harvest sustainability. The disadvantage is that strata-based plans may be infeasible because they lack the specific area information needed for developing operational logging plans. Conversely, area-based plans provide the information for implementing operational plans, but do not guarantee that the residual inventory structure is adequate to sustain long-term harvests.

Scope of the study

With the introduction of powerful micro computers and complementary software, it is now possible for complex forest planning issues to be dealt with at the logging division level, where the analyst(s) are more in touch with the structure, constraints, and potential of their forest. This trend will lead towards "bottom-up" planning, where the basic building blocks are spatially feasible area plans.

The time, effort, and cost of arriving at the true optimum of a MIP may not be warranted, especially when projected revenues, costs, and yields are all subject to a wide range of uncertainty. This paper proposes a method whereby managers are supplied with a number of good alternatives, thus providing them with better information and choices than does a single optimal solution. The results will provide spatially feasible alternatives that also meet long-term harvest objectives.

A procedure is presented for generating and integrating short-term, area-based plans (decades 1-3) within long-term, strata-based plans (decades 1-15). Timber production will be the only resource considered in this study. The Monte-Carlo integer programing (MCIP) technique (Conley 1980) is used to generate solutions for the 3-decade, area-based plan. These area-based plans are constrained by adjacency restrictions, volume flows, and net revenue flows. There will be no transportation network optimization once a schedule is established, because each harvest unit has only one logical route to the mill. This "tree" pattern is the result of both terrain conditions and the existing road network.

Results from the MCIP's are then used to formulate coordinated allocation choices within a 15-decade, strata-based plan, which will be solved as a linear program with the FORPLAN model (Johnson and Stuart 1987). A solution from this formulation provides a spatially feasible plan with specific yields and costs for decades 1 to 3, as well as a long-term projection of volumes and revenues for the remaining 12 decades.

The study is to be conducted on MacMillan Bloedel lands in British Columbia. The 4,000-hectare site is covered with mostly second growth timber that will serve as a long-term log supply for winter harvesting operations. Results of the study will be available in June 1988.

Objectives

There is a need to integrate short-term and long-term forest plans to ensure that both spatial feasibility and sustainable harvest goals are met. There is also a need to examine more than just one solution to the planning problem, especially in light of possible deviations from our current expectations of future revenues, costs, and yields. Specifically, the objective of the study is to identify three solutions to a 150-year timber harvesting plan that provide spatially feasible alternatives for the first 30 years, and also meet volume and net revenue goals for the subsequent 120 years. To provide for flexibility, additional spatially feasible alternatives must exist for decades 2 and 3, for each of the three integrated plans.

Methods and Procedures

There are three basic steps needed to accomplish the objective. First, estimates of long-term timber production and net revenue flows are determined. Second, harvest units are selected to form spatially feasible plans for the first 3 decades using the long-term volume and net revenue estimates as guidelines. Third, the three best area-based plans are incorporated into 150-year harvest schedules to determine their impact on future volume and revenue production.

Step One: Determining Long-Term Volume and Net Revenue Production

To arrive at our estimates of long-term timber and net revenue production, a 150-year LP is formulated using a strata-based approach. Using a Model 1 formulation (Johnson and Scheurman 1977), our objective function is to maximize present net worth (PNW), subject to the following constraints. First, a nondeclining yield (NDY) of timber that is not to exceed the long-term sustained yield (LTSY) of the forest is desired.

Second, it is preferred to have a minimum level of net revenue produced each decade to prevent the cutting of all high valued stands in the early time periods (each period is 1 decade). Third, the resulting inventory at the end of the planning horizon must be at least as large as the average inventory throughout the planning horizon. This is commonly referred to as the perpetual timber harvest constraint.

Finally, it is necessary to restrict the first 3 decades of harvesting to a specific geographic zone within the study site. Restricting the initial three-period harvest to a specific zone is needed because it would be unreasonable to plan harvesting in inaccessible portions of the forest. Using an undeveloped drainage as an example, early harvesting would be confined to a zone at the entrance to the drainage. As road construction progresses, more of the drainage becomes accessible, thus allowing more flexibility in the location of harvest units. In our example, harvesting (period 1-3) is restricted to an accessible area that contains mostly mature timber. This area is labelled zone A, and the remainder of the forest is labelled zone B. It is from within zone A that the area-based plans are generated. During periods 4 through 15, the entire forest is eligible for cutting.

The following procedure is used to determine what stands should be included in zone A. Successive LP's will be run with increasingly more hectares added to the zone until the harvest levels (periods 1-3) are not restricted by the availability of timber. Under a NDY constraint, these LP's will show an upward step in volume production after period 3 if the zone was limiting the initial cut. The point at which there is no discontinuity in the volume harvested indicates that the zone is of sufficient size, and will not be constraining the overall timber flow.

There will be approximately 70 timber strata (analysis areas) with multiple timing choices in the study. The FORPLAN model will be used to generate the linear program in Mathematical Programming System (MPS) format, and the LP software LINDO will be used to solve the problem. A typical LP formulation at this stage will have about 1,900 variables and 130 rows.

Step Two: Determining the Three Highest Valued Area-Based Plans

The results from procedure 1 will define the zone in which harvesting units are to be located. Within this zone, approximately 50 harvest units will be located. These units are designed and located to meet terrain conditions, maximum clear cut size, and logging system feasibility. Environmental policy dictates that no two adjacent units can be harvested during the same time period. Corresponding to the harvest units are about 50 main road projects and numerous secondary roads (roads and landings completely contained within a harvest unit). For the 3-decade problem, this represents around 300 integer variables [(50 units + 50 road projects) X 3 periods = 300 integer variables].

Monte-Carlo integer programming will be used to generate solutions to this area-based planning problem. The objective function is to maximize PNW subject to the volume and net revenue constraints found in the 15-decade LP, and constraints that prevent any two adjacent units from being cut in the same period. For simplicity, constraints that specify the maximum/minimum volumes of individual species are not included in the problem. Projected traffic flow over the roads will be far below capacity, so it is unnecessary to include these constraints.

There are two major methods followed to arrive at the three best solutions. In the first method, the MCIP is used to generate 200 feasible solutions (labelled temporary solutions) for the planning problem. This method, called random searches, is free to choose harvest patterns in all three periods.

In the second method, called selective searches, the three temporary solutions with the highest PNW's (TS1, TS2, and TS3) are selected for further analysis. The first period harvest pattern from these temporary solutions is fixed, and only periods 2 and 3 are allowed to vary. The two objectives of the selective searches are, first, to find better solutions, and second, to demonstrate that other alternatives exist even though the first period is fixed. This is useful information that demonstrates that flexibility is available in future periods, regardless of the action taken in period 1.

Finally, the highest valued solution found in each of the three selective searches is chosen as a "permanent solution" (PS1, PS2, and PS3), and subsequently used as a coordinated allocation choice within the integrated plans.

The random search method is described first. The MCIP algorithm is outlined in figure 1 and described below. It is basically a three-stage procedure (with each period representing a stage) in which harvest units are randomly selected for cutting at each stage. Random numbers are generated with a prime modulus multiplicative linear congruent random number generator (Schrage 1979). Random numbers are converted into binary variables (0 or 1) for each harvest unit. If a unit is assigned a value of 1, then it is to be cut in that period, otherwise it is assigned a value of 0, and will not be cut during that period.

Starting with the first period, all 50 units are eligible for cutting, so each is assigned a binary variable. The next step is to ensure that no two adjacent units are selected in the same time period. This is accomplished with an adjacency routine that sequentially reads in the binary variables for each unit. If a particular unit has a binary variable equal to one, then all adjacent units are set equal to zero. When the adjacency routine is completed, a spatially feasible pattern of harvest units has been established. At this point, the volume produced from the selected units is tested to see if it falls within the allowable tolerances. If not, we return to the start and generate a new set of binary variables, otherwise we have an acceptable solution in terms of adjacency and volume requirements, and we can proceed to the second period (stage).

The net revenue for this first period solution is not checked at this point because, through testing, it was found that fully checking each period offered no computational efficiency over

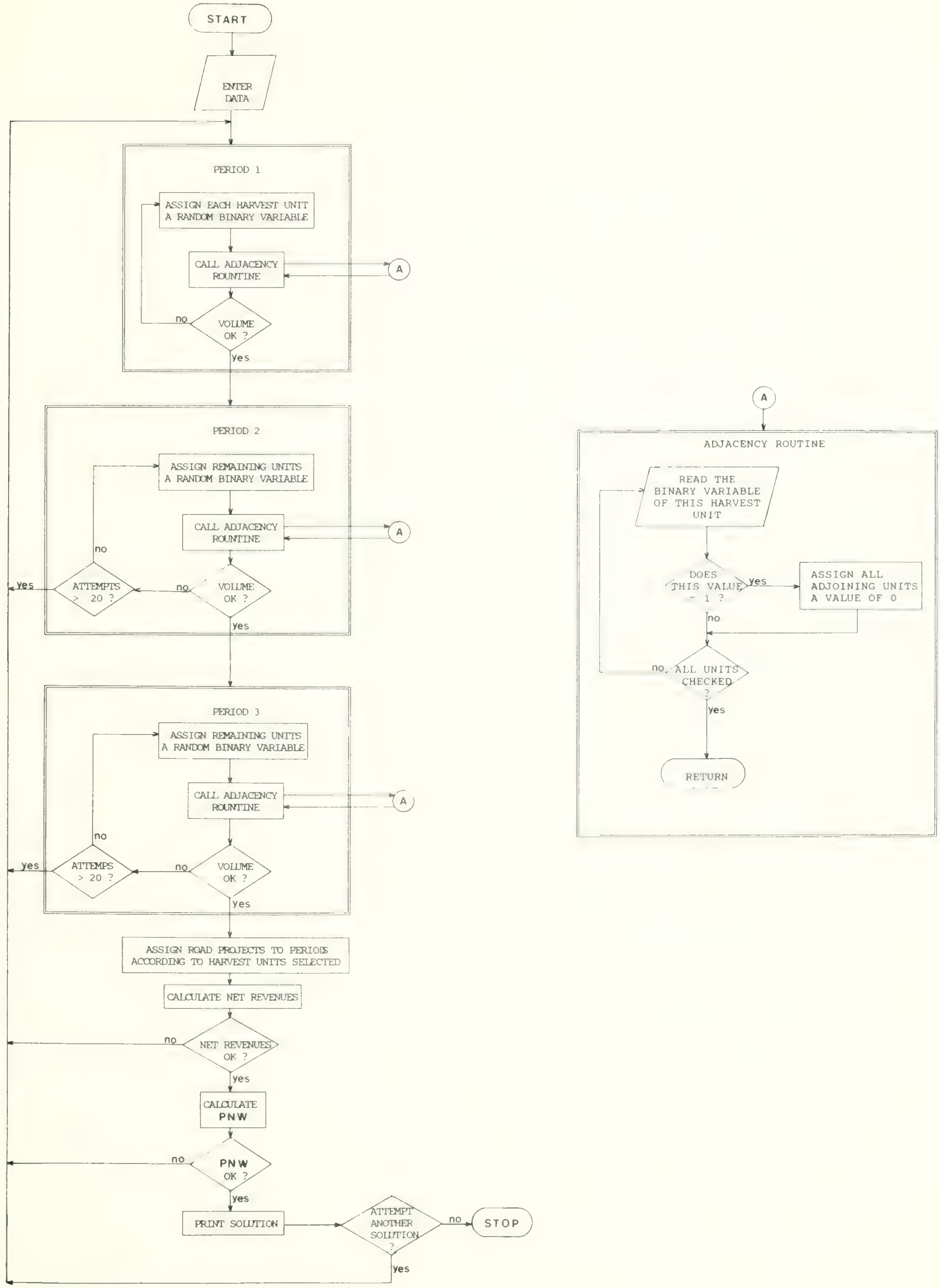

Figure 1.--Flow chart of the Monte-Carlo integer program.

checking an entire three-period solution. It takes very little time (about 1.5 seconds) for the algorithm to arrive at a three-period solution that meets adjacency and volume constraints. The minimum net revenue constraint drastically reduces the feasible region of the problem, and it takes approximately 10 minutes to generate a fully acceptable solution.

In period 2, harvest units that were selected in period 1 are no longer eligible for cutting, so binary variables are generated for the remaining units only. From this point on, the same procedures described for the first period case are repeated. If an acceptable solution cannot be found in 20 attempts, we return to the start and try a new first period solution. In most cases, a second period solution is found after about four attempts.

In the third period, the MCIP can only select units that were not cut in either of the preceding periods. If a solution can not be found in 20 attempts, we return to the start of period 1. Returning to the start of period 2, in an attempt to utilize the first period solution, failed to offer any advantage over completely starting over at the beginning of period 1.

When a feasible alternative to period 3 is found, the necessary road projects are assigned and the net revenue for each period is calculated and checked against a threshold value. If unacceptable, the solution is rejected, otherwise it is checked against a minimum PNW value. A solution that passes this final test is recorded as a feasible area-based plan (previously defined as a temporary solution).

Having completed the 200 random searches and identifying the three highest valued solutions (TS1, TS2, and TS3), three selective searches are initiated. Other than fixing the first period harvest pattern and raising the threshold PNW to eliminate low valued solutions, the MCIP algorithm operates the same way as described in the random search method. Each selective search is used to identify five new solutions. The highest valued PNW solution from each group of five selective searches is then chosen as a permanent solution (PS1, PS2, and PS3). Figure 2 illustrates how random and selective searches are used to determine the area-based plans that are subsequently used as CAC's. The MCIP will be written and compiled in Turbo Basic, and run on a Compaq Deskpro 386 computer.[2]

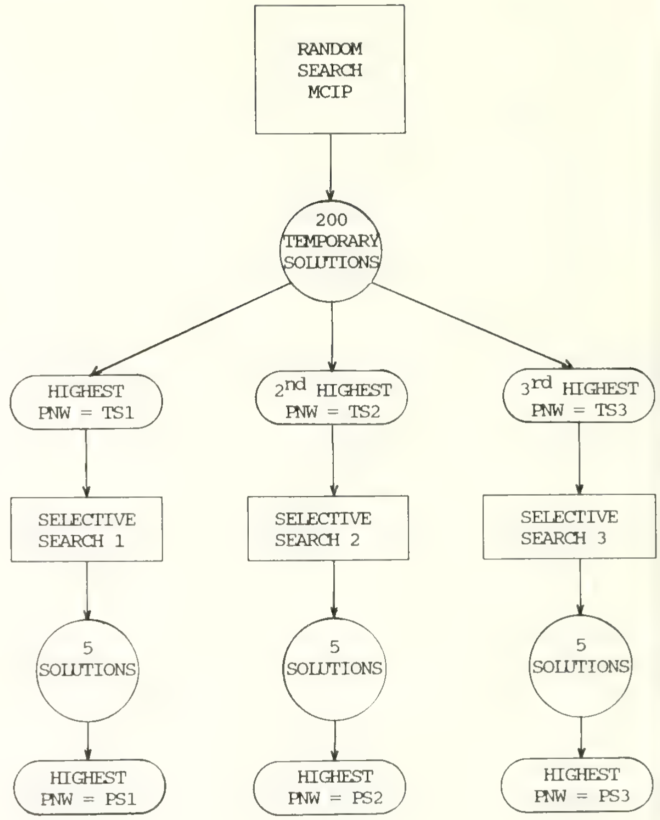

Figure 2.--Relationship between random and selective searches in establishing area-based plans.

Step Three: Integrating the Area-Based Plan With the Long-Term Strata-Based Plan

The three area-based plans identified above are then incorporated into 15-decade linear programs. These integrated plans are labelled ILP1, ILP2, and ILP3. Using the FORPLAN model, each area-based plan is treated as a coordinated allocation choice (CAC) that was selected from the zone containing the harvest units. The CAC contains all the hectares of the analysis areas that are within the harvest units selected for cutting. When implemented, the CAC forces a cutting schedule for the existing stands on each respective analysis area. It is important to note that the timing choices of the regenerated stands that result are not restricted by this method. The implication of this is that while this spatially feasible pattern occurs now, it does not necessarily repeat itself in subsequent rotations.

Other than forcing a particular set of AA's and road costs into the first three periods, these integrated linear programs (ILP's) are typical strata-based models. The objective function is to maximize PNW subject to an even flow of timber, nondeclining net revenues, and a perpetual timber harvest constraint.

For the purposes of comparing the three integrated plans, it is desirable to have a uniform flow of both volume and net revenue during periods 4 through 15. Volumes are allowed to fluctuate slightly (1-2%) from period to period, while net revenue is not allowed to decline. This provides enough flexibility to spread harvesting of the low valued stands throughout the planning horizon. Since the first three periods are fixed, the problem is reduced to finding a uniform cash flow over the last 12 periods, subject to minor volume changes.

[2]The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of a service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Discussion

The procedures outlined here provide a linkage between rea-based and strata-based planning. It allows us to overcome he problems associated with each of these approaches. Spaially feasible plans can be generated and their long-term mplications on volume and revenues can be assessed. While Monte-Carlo integer programming cannot guarantee an "optinal" solution to the standard mixed integer programming roblem encountered in area-based planning, it is capable of uickly generating numerous high valued alternatives. This epresents a considerable improvement over traditional methds where arriving at one or two feasible alternatives is a lifficult task. When incorporated into FORPLAN formulations, he long-term effects of the MCIP solutions can be assessed, hus reducing the potential for disruptions in future harvest evels resulting from a myopic selection of harvest units.

The MCIP technique is advantageous in that it can quickly dentify alternative harvest patterns should our assumptions hange over time. It allows us to proceed with our immediate lan (period 1), knowing that flexibility exists in the selection of harvest units in subsequent decades.

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GIS PIP: The Role of the Geographic Information System In the Plan Implementation Process

Reuben Weisz[1]

Abstract.--This paper describes the role of a GIS in the plan implementation process. The approach taken is to take an optimistic look at each phase of plan implementation and answer the following question: How can a GIS be used at this stage?

Integrated Resource Management (IRM) is defined as a land management philosophy which recognizes that all natural resources are connected through an intricate series of interrelationships. In order to recognize these interrelationships when a Plan is implemented on the ground, our Region has adopted a 13-step process which is called IRM. The 13 steps are:

1. Review Forest Plan
2. Develop Project Concept
3. Conduct Extensive Reconnaissance
4. Prepare Feasibility Report
5. Update Forest 10-Year Implementation Schedule
6. Conduct Intensive Reconnaissance, Survey, or Design
7. Generate and Compare Alternatives
8. Alternative Selection
9. Prepare NEPA Documentation
10. Create Project Record
11. Prepare Project Action Plan
12. Field Implementation
13. Monitoring and Evaluation

There is another process in our Region which has the initials IRM (Information Resources Management). When used in the context of information systems management, IRM refers to the process of managing our information resources--i.e.,

1. Information Systems Management
2. Data Processing
3. Data Analysis
4. Information Output
5. Information Use.

A GIS uses the five subsystems of Information Resources Management with data that is spatially locatable. In other words, in a GIS, a locational identifier associated with each item of data indicates where on the surface of the earth the information is located.

In order to facilitate the collection, processing, and display of data in an integrated resource environment, our Region is promoting the use of Geographic Information Systems (GIS) whenever the benefits of GIS are greater than the costs. This manuscript describes the benefits of using a GIS at each phase of Integrated Resource Management. (Henceforth, in this paper, "IRM" will mean "Integrated Resources Management".)

Phase 0--Pre-IRM GIS Work

Often the high front end costs of establishing a GIS can not be justified by its application to an individual project. The initial acquisition of hardware, software, and data is a time consuming and expensive undertaking which should not be underestimated. However, once a GIS is in place, the cost per project may be less than or equal to the comparative cost of a similar IRM process done manually. Also, the quality of the analysis and the project should improve and the likelihood of successful appeals should decrease with the availability of better information in the IRM process.

[1] *Operations Research Analyst, U.S. Department of Agriculture Forest Service, Albuquerque, N.M.*

The remainder of this paper describes how a GIS can be used in the plan implementation process. However, before a Forest can capture these benefits tomorrow, the following investment in GIS must be made today:

1. The Forest must decide to use GIS.
2. The Forest must budget for GIS. This includes the cost of hardware, software, data entry, data acquisition, and personnel. (At least one individual on the Forest will need to be designated as a GIS coordinator.) Beginning in FY 1988 the Regional Office budget includes recognition of GIS needs. The Forests need to make certain that these costs are incorporated into their Plan Implementation Schedules, as well.
3. Develop knowledge and experience with GIS through training and "hands on" experience in developing your Forest's GIS.

Once these three steps have been completed a Forest is in the position of being able to benefit from using GIS PIP (a GIS in the Plan Implementation Process). The remainder of this paper assumes that a Forest is ready to go with GIS PIP.

Phase 1--Review Forest Plan

A GIS provides us with another way of reviewing the Forest Plan. In map form, it provides the user with a description of the existing condition of the forest, as well as a vision of the forest of the future.

Mechanically, this is accomplished by overlaying the study area boundary with each relevant resource layer that is currently in the GIS. Products produced by the GIS at this stage include graphic output in the form of maps, and acreage summaries.

When reviewing the plan, we should first view the overall landscape. A GIS can allow us to visualize a complete picture of the spatial composition of vegetation, and the general location of facilities, roads, trail locations, culturally and environmentally sensitive areas, land ownership and use patterns, and other basic resource information in the project area.

This information can be used to evaluate locations for projects to be implemented. A part of Phase 1 is determining what Plan direction is applicable to the project area. A GIS can include narrative information such as standards and guidelines. In other words, if a location is known, a query can indicate what standards and guidelines apply to that area.

If standards and guidelines are not in the GIS, the GIS can still help to locate the standards and guidelines in the Plan. This can be accomplished by querying the GIS for an inventory of resources in the project area. Many standards and guidelines are tied directly to the characteristics of the land. For example, if the GIS indicates that the project area is in mixed conifer under 40% slope, the standards and guidelines in the Plan may indicate that we must that we must manage for the hairy woodpecker, elk, red squirrel, and turkey.

Alternatively, a GIS can help us to locate more specifically where a project should be implemented. For example, let's assume that an activity must take place where a specific combination of soil, slope, and vegetation occur. The GIS could be asked to display all occurrences of this combination of conditions. If alternative locations exist, the GIS could be used to select the best location for a more detailed analysis later on in the IRM process. In the later phase of IRM, the GIS could be used to "zoom in" on the best location with more site specific analysis at the project level.

This phase of IRM marks the beginning of project scoping (NEPA definition). By displaying the characteristics of the project area in tabular and map form, the GIS will provide resource specialists with information that will indicate potential ICOs. It can be used to indicate if this location has unique resource opportunities that are of interest to the public or are of interest to a specific management concern.

For example, a part of our land ethic and a part of our plan indicates that we are going to obliterate so many miles of unneeded roads. The GIS can be used to indicate if an opportunity for this activity exists in the project area. A part of Phase 1 of IRM in the Citizen Participation PIP is maintaining forest LMP contacts. If there is a citizen group that is interested in this topic, we can indicate that the road density will be reduced from some figure "X" to some figure "Y" in the project area. Or a GIS could be used to display exactly which roads in what locations could be closed. A map display might be more relevant to citizen participants if it can be comprehended more easily than numerical data. Also, many issues and concerns deal with the spatial aspects of plan implementation and not with statistical averages. That is, whether or not a specific road from point "A" to point "B" will be closed is more of an issue than whether or not the road density will change from "X" to "Y". A GIS is an excellent communications medium for public involvement.

The GIS can be used to define the influence area of the project considering potentials for direct, indirect, and cumulative environmental effects. For example, a display of the location of all projects underway and in the 10-year plan implementation schedule will provide an early warning of potential cumulative effects.

This illustration will facilitate developing a consistent set of projects. For example, the display of a developed recreation construction project without a road or visa versa would indicate a lack of coordination that would need to be remedied.

Phase 2--Develop Project Concept

The purpose of Phase 2 is to determine precisely what this project will be designed to do and why. The data and maps produced by the GIS in Phase 1 will be used in Phase 2 to develop the site specific Icos and objectives for the project(s).

The identification of site specific ICOs may lead to the identification of additional themes that are required in the GIS. These may either be new resource layers that are not contained

in the standard regional and Forest-specific resource layers, or existing layers which require more site specific detail for project analysis. If additional automated map information is needed, its acquisition or preparation must begin now, prior to its use later on in the IRM process.

When data requirements for a specified project are defined they must be based on the ICOs. The only information needed is what is required by the decision maker to address the decision that needs to be made.

The BLM (Webster 1987) uses a process called "cartographic modeling" which is a useful means for defining what information is needed by a decision maker. Cartographic modeling provides a conceptual framework for defining what information is needed.

For example, let's assume that the Plan says that a hiking trail will be constructed in the project area. What information is needed to formulate and evaluate alternatives?

The conceptual framework could be structured as follows:

THE QUESTION	CRITERIA	FACTORS	RESOURCE LAYER
Which corridor is most suitable for a hiking trail?	1. Erosion Hazard	Soil Properties, Vegetation, Slope Steepness & Complexity	Multilevel TES (Terrestrial Ecosystem Survey) DEM (Digital Elevation Model)
	2. Hiking Difficulty	Soil Properties, Vegetation, Slope Steepness & Complexity	Multilevel TES DEM
	3. Visual Quality	Views, Attractiveness	VQO Variety Class Distance Zone
	4. Recreation Opportunities	Recreation Attractiveness, Physical Setting	CR Maps: Historic, Prehistoric, Arch. Sites ROS Class
		Noise	Dispersed User Density Facilities Transportation
		Water Quality, Supply	Potable Water Water Bodies
	5. Cost	Soil, Vegetation, Slope, Erosion Hazard	Multilevel TES

Note: As the above cartographic model indicates, some re source layers such as the Multilevel TES Map have multipl uses within a GIS analysis. Also, just because a needed layer o information is defined, this does not mean that we have to go ou and digitize a new map. Often, the recommendation or manipu lation of existing data can give us the desired information. Fo example, a distance zone layer was desired to evaluate visua quality. However, instead of digitizing a new map with fore ground, midground, and background indices, it may be possibl to get the required information by running a viewshed analysi subroutine using the DEM (Digital Elevation Model) data tha is already in the GIS. Similarly, if a map of fragile soils wa desired and didn't exist, it might be developed by analyzin information already contained in the TES (Terrestrial Ecosys tem Survey), DEM (for slopes and elevation information), an recent fire area maps.

Phase 3--Conduct Extensive Reconnaissance

The purpose of this phase is to determine by means of a brie field trip, if the project concept developed in Phase 2 will work The GIS is involved with this phase in several ways.

First, as indicated in the discussion of Phase 1, the GIS ca indicate where on the ground Phase 3 should take place. Fiel time can be saved as ID Team members visit only those area that have been pinpointed by the earlier analysis with the GIS

Second, tabular data, statistical analyses, maps of individua layers, and overlaid maps developed by the GIS provide tool that are useful prior to, during, and after extensive reconnais sance.

Third, several products of extensive reconnaissance have direct tie to the GIS. These include the following:

a. Map or maps of project planning area showing known resource information.

b. Statistical reports on data in project planning area.

Phase 4--Prepare Feasibility Report

In this phase a Project Feasibility Report (PFR) is prepared The PFR demonstrates whether or not the project is bot technically feasible and economically feasible. The line office makes a decision based on the report to proceed or not t proceed.

The project initiators either prepare the PFR or, at a mini mum, provide information to the line officer concerning th project's feasibility. GIS information developed in the earlie phases will be one source of useful information.

GIS data related to technical feasibility might include th location of cultural resources, location of wildlife habitat an riparian vegetation, inventory of sensitive soils, VQO objec tives, etc. The GIS could indicate how a variety of technica feasibility factors interrelate with each other through the devel

opment of map overlays and other cartographic modeling techniques.

GIS data can contribute to the analysis of economic feasibility as well. For example, road costs are related to the status of existing roads, distance from sources of aggregates, location of sensitive resource areas, existing soil types, and slope conditions. Linkages with resource data components of the GIS such as the stand data base can indicate information on the benefits to be derived from the resources in the project area. For example, stand data would indicate the volume that is available for harvest--i.e., timber benefits.

GIS products from this phase that would be included in the PFR are:

a. Maps delineating
   i. the above items,
   ii. proposed location of resource project area,
   iii. pertinent known information within and adjacent to the project area, and
b. data indicating potential outputs and impacts.

Phase 5--Update Forest Plan 10-Year Implementation Schedule

The main objective of this phase is to update the Forest's 10-Year Plan Implementation Schedule which is maintained on a spreadsheet. The purpose of the spreadsheet is to assure that projects are scheduled in a sequence over time that works toward the desired future condition of the Forest.

Another achievement of Integrated Resource Management is that projects be identified together in an integrated manner within the same area of land. The GIS can be used to illustrate the group of projects for a specific, contiguous area of land needed to achieve the desired future condition. The pattern of implementation over space must be integrated with the pattern of implementation over time. This provides the user with a description of the existing condition of the forest, as well as a vision of the forest of the future. This will enable subsequent project initiators on this and related projects to see where they fit into the big picture.

Phase 6--Conduct Intensive Reconnaissance, Survey, or Design

The objective of this phase is to acquire all of the specific on-the-ground knowledge of the project planning area and its resources necessary to design a project that fully addresses the ICOs, sale objectives, and appropriate resource objectives. All site specific information needed for the project environmental analysis is collected during this phase (e.g., road location, cultural resource survey, T&E survey, fence location, etc.).

Products of this phase include more site specific data which is entered into the GIS. For example, if a timber sale is proposed within the project area, the boundaries of cutting units can be digitized and more precise data by cutting unit can be defined. This clarifies within the GIS the specific situation involved in this project analysis.

Phase 7--Alternative Generation and Comparison

The objective of this phase is to develop a reasonable range of alternatives including a "No Action" alternative. At this stage, a GIS with a variety of cartographic modeling procedures can be used.

One approach is the computer overlay mapping technique which is an automated version of the old plastic overlay approach which was popularized by Ian McHarg. By assigning different weights to different resource layers according to the objectives of the alternative, an alternative spatial pattern can be developed for the project area.

The overlay approach allows various resource layers to be integrated into a new map which displays resource interactions in the project area. For example, overlaying a road map on top of a map of critical wildlife habitat will illustrate areas of possible conflict between transportation development and wildlife protection.

A new layer could be generated for each alternative that is formulated. For example, one layer could indicate which specific cutting units would be treated if an alternative for a timber sale were adopted. Once this new layer is digitized, it could be used in conjunction with existing layers in future analyses.

Other GIS techniques can be used in the analysis and development of alternatives. One such example is the creation of buffer zones. A buffer zone is an area within a specified distance from a particular feature on a map. For example, a buffer zone around a proposed road may be used to define the area of wildlife habitat that may be potentially impacted by the road. Acreage summaries of affected areas, as well as mapped information, can be produced by the GIS.

Another example of a useful GIS technique is something called "viewshed analysis." A viewshed map can indicate if resource development (a mining operation, timber clearcut, etc.) is within the view of a proposed campground.

In addition to a variety of GIS techniques, other approaches to formulating and evaluating alternatives are available. Pure subjective judgment and experience can be utilized to generate alternatives if desired. Or, if desired, more automated approaches (ranging from project analysis spreadsheets to network analysis models) may be employed. However the alternatives are formulated, they may be depicted in map form and evaluated (for example, acreage and output summaries) using the GIS. The comparison of alternatives may be based, in part, on the output of the GIS.

GIS products from this phase could include map output for each alternative, as well as displays and tabular summaries of the resource attributes of each alternative.

Phase 8--Alternative Selection

In this phase, a proposed action is selected by the appropriate line officer. The line officer may include instructions to modify or refine any or all of the previously conducted analysis, which will require recycling back to previously conducted phases.

Phase 9--NEPA Documentation

The purpose of this phase is to complete environmental documentation. Products of this phase may include environmental documents (such as EA, FONSI, DN, EIS, ROD) and/or a categorical exclusion. These NEPA documents can incorporate maps and data produced by the GIS for a documentation of the input data and rationale for developing alternatives, as well as a description of the effects of alternatives.

Phase 10--Create a Project Record

The purpose of this phase is to have all pertinent information concerning the project in a single collection packet at one location for easy access. With a GIS this would include all relevant hardcopy output and any necessary references to data residing within the GIS data base or procedures used to manipulate the data for the analysis of this project. Material, relevant computer files need to be archived if this is cheaper than the expected cost of regenerating them at a later date. The availability of an on-line GIS system for answering some of the queries from the public during the citizen involvement process gives the forest a real-time project information system in addition to a static set of project records which are available on the shelf. Phase 10 captures the results of the previous phases in automated form. This may require more digitizing and data entry.

Phase 11--Prepare Project Action Plan

The objective of this phase is to specify who does what, when, where, and how the project is implemented on the ground. Products of this phase include final maps, layouts, surveys, designs, etc. Although alternative mapping techniques (such as the Autocad software which is currently employed by engineers in our Region) can be used, the GIS may be applicable in this phase as well.

Phase 12--Field Implementation

The purpose of this phase is to accomplish the project in accord with the final decision. This is the move from the paper product (produced in part by the GIS) to the ground. It is conceivable that a reference to the paper product will be necessary during this phase.

Phase 13--Monitoring and Evaluation

The objective of this phase is to monitor implementation and completion of the project and to evaluate the success or failure of project design.

The GIS will prove useful in a future evaluation of the project by tiering treatments to the ground. It should be relatively easy to locate projects and evaluate whether or not the treatment met the long term objectives and goals for the area. For example, this will give us a data base to say that, on a given land type or habitat type, such and such a mitigation measure worked (or didn't work).

While the project is being implemented and afterwards, it may be necessary to update the GIS data base. For example, a project design may be adjusted when on-the-ground conditions warrant (e.g., finding a previously unknown spotted owl territory or cultural resource site). Products of this phase will include an updated GIS as well as a project monitoring report.

Concluding Thoughts

As described in this paper, GIS can be used successfully during each phase of Integrated Resource Management (IRM). IRM is defined as a land management philosophy which recognizes that all natural resources are connected through an intricate series of interrelationships.

These interrelationships are complex and are not always well understood. The purpose of GIS is to help us comprehend these interrelationships. To maximize the utility of GIS, we must understand the interrelationships between GIS and IRM.

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Modification of an Initial Attack Simulation Model to Include Stochastic Components

Jeremy S. Fried and J. Keith Gilless[1]

Abstract.--The California Fire Economics Simulator-Initial Attack Module (CFES-IAM) is an MS-DOS micro-computer based planning tool developed for the California Department of Forestry and Fire Protection (CDF). CFES-IAM version 1, now in use, is a deterministic simulator which models initial attack on a limited number of representative wildland fires using data that describes an "average" fire season. Modification to better reflect real-world variability in wildfire occurrence, behavior, and initial attack control efforts is now in progress. CFES-IAM version 2, now under development, will be a clock-driven, next-event simulator. It will draw many of the key parameters describing simulated fires (e.g., time of day, fire rate of spread, and fireline production rates) from stochastic distributions. The parameters of these distributions are now being estimated for each CDF planning unit using local data. CFES-IAM version 2 will calculate expected values and confidence intervals for annual fire losses and control costs on a planning unit using the results from repeated simulations.

The occurrence of wildfires, the physical behavior of these fires, and the effectiveness of initial attack efforts to control them are all phenomena characterized by considerable uncertainty. Most prior applications of stochastic simulation to these problems have been rather narrowly focused (Martel 1982). Attempts at an integrated stochastic representation of these phenomena have never advanced to widespread implementation for a variety of computational, budgetary, and administrative reasons (Bratten et al. 1981, Mills and Bratten 1982).

The California Fire Economics Simulator-Initial Attack Module (CFES-IAM) is an MS-DOS micro-computer based planning tool developed by the authors for the California Department of Forestry and Fire Protection (CDF) (Fried and Gilless 1988). CFES-IAM version 1 is based upon the same deterministic simulation concepts as the U.S. Forest Service's Initial Action Assessment model (U.S. Department of Agriculture, Forest Service 1985). While CFES-IAM version 1 has been well received within the CDF, the limitations of its conceptual framework have already motivated efforts to develop a new version of the simulator that reflects real-world variability in wildfire occurrence, behavior, and initial attack control efforts.

[1]*Associate Specialist and Assistant Professor, respectively, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720*

CFES-IAM version 2 will be a clock-driven, next-event simulator. It will draw many of the key parameters describing simulated fires (e.g., time of day, fire rate of spread, and fireline production rates) from stochastic distributions. The parameters of these distributions are now being estimated for each CDF planning unit using local historical fire records. Version 2 will calculate expected values and confidence intervals for annual fire losses and control costs on a planning unit using the results from repeated simulations, providing critical data for the CDF to evaluate its organization's ability to respond to both moderate and extreme fire seasons. This paper documents the ongoing modification of CFES-IAM version 1 to reflect the stochastic character of wildfire occurrence, behavior, and initial attack control efforts.

Fire Occurrence Module

Multiple fire starts are a major problem for the CDF. To permit realistic simulation of this phenomenon, CFES-IAM version 2 will necessarily be a next-event, clock-driven simulator. After processing an event (e.g., fire ignition, arrival of a fire-fighting resource, or fire containment), the simulator's "clock" will advance to the next event, explicitly recognizing the importance of chronological and spatial proximity. Further-

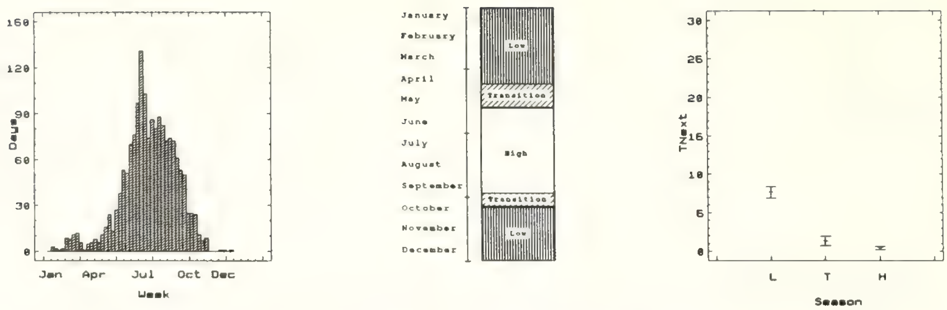

Figure 1.--(a) Number of fires per week over 5 years. (b) Low, Transition, and High fire seasons. (c) Ninety-five percent confidence interval plots of TNext, by fire. (All data are from historical fire records for the Nevada-Yuba-Placer ranger unit, California Department of Forestry and Fire Protection.)

more, it is important that version 2 be able to generate fire starts in patterns that are consistent with an area's fire history.

Four evaluation criteria determined the nature of CFES-IAM version 2's fire occurrence module. Close correspondence was sought between generated sequences of fires and historical fire records with respect to:

1. Distribution of the number of fires per year.
2. Distribution of fires by time of day.
3. Frequency and severity of multiple fire days (days with more than one fire).
4. Distribution of fires by season (or time of year).

Correspondence between the historical and generated distributions of number of fires per year is important for capturing the scale of the fire management problem. Agreement between historical and generated distributions for time of day is critical for simulating initial attack on multiple fire days, and to reflect the fact that some firefighting resources can only be used during daylight hours. Correspondence between historical and generated sequences of fires with respect to the frequency and severity of multiple fire days is necessary to evaluate the ability of the CDF to deal with severe fire seasons (i.e., those characterized by longer response times and decreased response capability). Finally, a match between historical and generated fire sequences with respect to the distribution of fires by season (or time of year) is important given seasonal differences in fire organizations' staffing and response capabilities.

Before finalizing the model structure, we analyzed CDF databases containing the date and time of occurrence, location and size at arrival and upon control for each wildland fire since 1981 in three ranger units located in the western foothills of the Sierra Nevada and on the eastern margin of the San Joaquin Valley. Altogether, these databases contained information on 4,000 fires. Distributions developed for the Nevada-Yuba-Placer (NEU) ranger unit are presented here to illustrate the structure of the occurrence module.

Most next-event, clock-driven simulators are based upon a single distribution describing the time between events. This approach was rejected because when used to simulate wildland fires in California, the resulting distribution of fire occurrenc by time of day failed to demonstrate the diurnal pattern charac teristic of real fires. The short duration of most fires fought b the CDF pointed to an alternative approach, one in which fir ignitions for any day are generated independently of those fo preceding or subsequent days. This method requires the estima tion of not one, but three distributions, which together ca generate a sequence of fire ignitions over the course of a day

California's annual pattern of fire occurrence suggested th division of the calendar year into three seasonal classes o relatively homogeneous fire frequency, referred to here as th Low, Transition, and High fire seasons. Inspection of histo grams of the number of fires per week (fig. 1a) and Tuke multiple range tests of the time between fires (TNext) by wee helped to determine these divisions (fig. 1b). The Transitio season typically included 3 to 5 weeks in the spring and anothe few weeks in the fall when fire incidence was higher than in th Low season but less than in the High season. For all three range units, mean TNext was significantly different for each season a shown by Means/95 % confidence interval plots (fig. 1c).

The distributions that best described the probability o occurrence (Fireday), number of fires per day (Multiplicity and time of day (Tod) of the fires were identified for eac season. Fireday, defined to be 0 for days on which no fire occurred and 1 otherwise, was easily characterized by a Be noulli distribution for each season. Histograms showing th relative frequency of Multiplicity by season, for days on whic fire(s) occurred, led to the conclusion that a geometric distribu tion best described the transform (Multiplicity-1) (fig. 2 Although the degree of Multiplicity represented in the Low an Transition seasons was sometimes insufficient to calculate chi squared statistics, the fit of these geometric distributions ove all seasons combined was acceptable, and far better than an logical alternatives such as the exponential distribution.

Unlike Fireday and Multiplicity, Tod exhibited no seasona differences. Thus, a single Tod distribution was estimate Frequency distributions of Tod varied in appearance, but all ha central tendencies when left-shifted 5 hours (so that 0 corre sponded to 5 a.m. and 23 to 4 a.m. the next day). Some range units' Tod distributions exhibited a broad peak between 11 a.n

and 7 p.m., and were best fit by beta distributions normalized to a 0-1 scale. Others, like the NEU ranger unit's Tod distribution, had high, narrow frequency peaks from 12 p.m. to 4 p.m., and were best fit by Poisson distributions (fig. 3).

Experimentation with this module has shown that it generates sequences of fires with TNext patterns quite similar to those of historical fires. The central tendency and variability of the total number of fires in these generated sequences compare favorably to their historical counterparts.

Attack Module

The sensitivity of CFES-IAM version 1 to variations in dispatch and firefighting productivity prompted the development of a stochastic attack module to represent these phenomena in version 2. For a simulated fire, the attack module generates initial attack strategy (i.e., head, flank, or indirect attack), tactics for firefighting resources capable of more than one kind of line production (e.g., mobile attack, hoselay, or handline for engines), and sustainable line production rates for firefighting resources, contingent upon the location, time, spread rate, buildup time, and dispatch level that define the fire. The attack module does not address variability in dispatch due to such factors as multiple fires, time of day, and fire danger as they are implicitly treated by the occurrence module.

Unfortunately, the fire literature provided no guidance for selecting strategies or tactics, and no information on production rates beyond tables of average rates by fuel and resource type. These tables, which are often based on only one observation per cell, provided insufficient information to serve as the basis for any kind of stochastic treatment. Ideally, we would like to directly measure the production rates of many firefighting resources on many fires and fuel types; unfortunately, past efforts of this type have been less than unqualified successes, largely due to the insurmountable logistical problems in deploying non-firefighting observers to measure ongoing line construction activity. Diligent researchers commanding small armies of earnest student observers spread throughout the state have been lucky to record 100 observations of line construction in a year, spread over 12 to 15 firefighting resource types, 5 to 8 fuel types, and 5 slope classes. Rather than launch another such (doomed) attempt, we opted to tap the knowledge of the experienced firefighting professionals who directly supervise the construction of fireline and make daily judgments about productivity when deploying firefighting resources at initial attack fires. The most practical way of accomplishing this was to survey fire engine captains, handcrew bosses, and dozer operators to solicit their expert assessments of site specific productivity for the types of firefighting resources that they command.

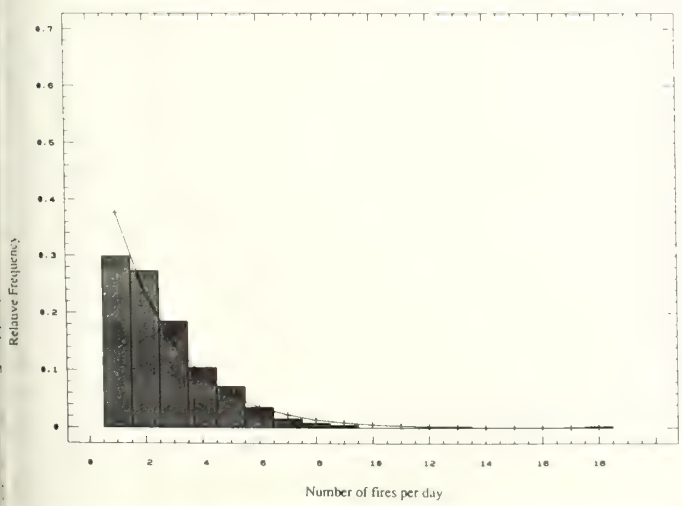

Figure 2.--Geometric Multiplicity distribution fitted to historical fire records for the Nevada-Yuba-Placer ranger unit, California Department of Forestry and Fire Protection.

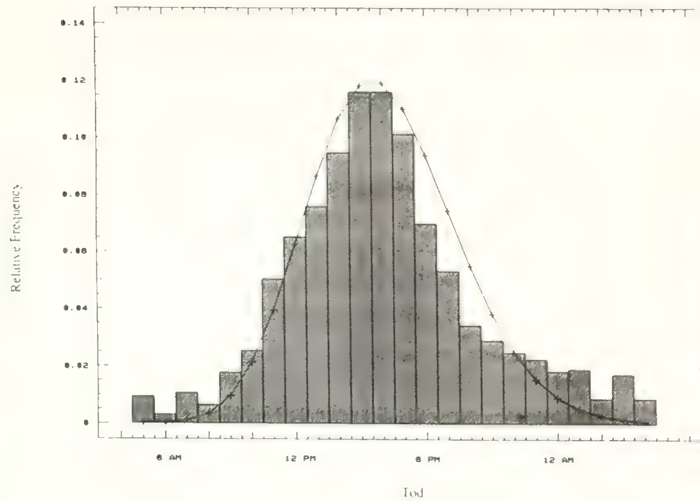

Figure 3.--Poisson Time of day (Tod) distribution fitted to historical fire records for the Nevada-Yuba-Placer ranger unit, California Department of Forestry and Fire Protection.

Because strategies, tactics, and production rates can be affected by local conditions, such as lava dikes, ubiquitous fences, or topography, we elected to conduct the attack survey at the ranger unit/contract county level, relying on local firefighting professionals to provide this information for the areas they know best. The survey is administered via a form for each unique combination of fuel, slope, and habitation density (control condition) on a ranger unit, accompanied by photographs depicting the fuel and topography of a particular location representative of that control condition. For the two ranger units surveyed thus far, this required one or two forms for each of three or four fire management analysis zones (FMAZs).

Each form contains a section for entering the percentage of fires, by dispatch level, on which the respondent would employ a head, flank, or indirect attack. For engine captains, an additional section queries for the percentage of fires for which mobile attack, hoselay, or handline tactics would be used for each of these strategies. Survey estimates of the relative probabilities of the different strategies and tactics are averaged for each control condition and dispatch level on a planning unit.

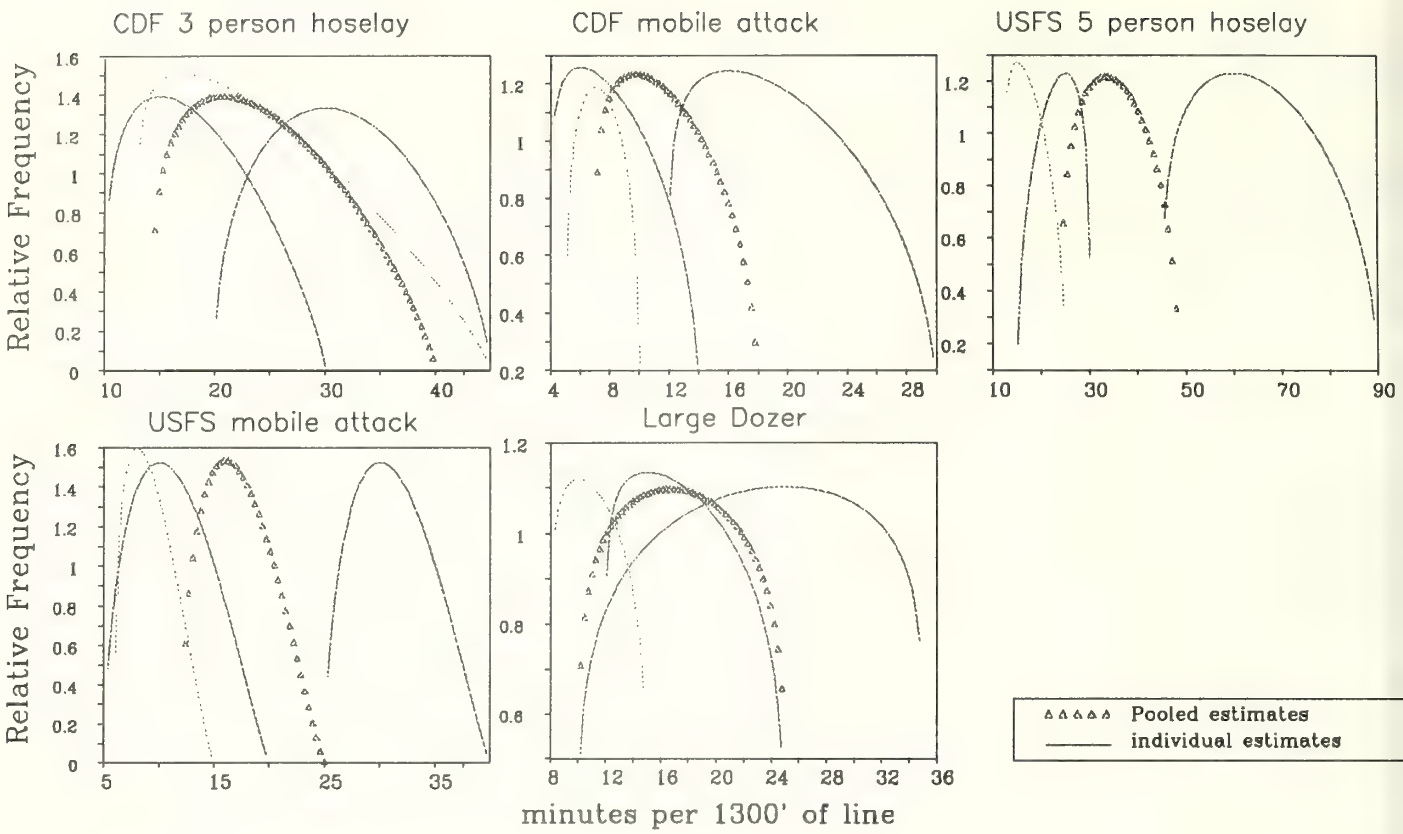

Figure 4.--Beta distributions of the time required to complete 1,300 feet of fireline in grass fuels for five equipment/tactics combinations (distributions derived from individual estimates indicated by solid lines; from pooled estimates, by triangles).

Before deploying firefighting resources to a simulated fire, CFES-IAM version 2 will randomly select a firefighting strategy and engine tactic on the basis of these probabilities.

On a final section of the survey form, the firefighter enters information pertaining to the line production rate for the resource type that he or she supervises. This includes an estimate of the best possible, the most likely, and the worst possible production rates. These are defined as the rate when everything is functioning perfectly with fresh, motivated personnel, the rate one would expect to see most of the time and the rate on a day when everything seems to go wrong, respectively. In addition, participants are asked to estimate an increment such that 50% of the time actual production rates will fall in the range from "most likely - increment" to "most likely + increment." All production rates are estimated as the number of minutes to construct x feet of held fireline, where x depends on the fuel (500 feet for brush and coniferous timber, 1,300 feet for grass and oak woodland); thus, smaller numbers of minutes imply faster production rates. This question format was employed because firefighters rarely think in terms of production rates but *do* make daily judgments about the time required to complete a section of fireline.

We generated beta distributions of the number of minutes to construct a length of fireline from the best, most likely, and worst case estimates, adapting a technique originally develope for probabilistic PERT analysis. The estimates of the incremen defining a 50% range were used as a check on the standar probabilistic PERT assumption that the standard deviation i one-sixth the range from the worst to the best time, an eventually to generate estimates of variance to be used i estimating the beta distributions. Distributions for differe types of resources in grass (fig. 4) and brush (fig. 5) ranged fro symmetric to highly skewed, and from narrowly concentrated nearly uniform random. For example, hand crew bosses pr vided estimates that generated concentrated distributions, whi USFS engine captains' responses for handline production b engine crews described distributions with virtually no pea (i.e., their estimate of increment such that the interval "mo likely - increment" to "most likely + increment" spanned mo of the range from best to worst time). Variances derived fro individual estimates of production rate parameters were ave aged for each resource type/control condition combinatio increasing the similarity among distributions within each. Th individual estimates were averaged for each combination estimate pooled distributions for use in CFES-IAM version Where there is little overlap among distributions based o individual estimates, (e.g., the USFS 5 person hoselay in gras fig. 4), it may be preferable to also include data from adjace

ranger units to arrive at a more robust pooled distribution. It is interesting to note that the pooled (and most individual) distributions are either symmetric or skewed towards faster production rates (i.e., fewer minutes to complete the fixed distance), indicating the respondents' belief that firefighting forces usually perform closer to their best than to their worst, a result consistent with the probabilistic PERT literature. This skewness suggests that accurate estimation of a symmetric increment may be impossible, and that a one-tailed estimate (e.g., what is the time to completion that you would expect to exceed only 1 out of 10 times?) may elicit better estimates of variance.

The data entry module of CFES-IAM version 2 will query for the production rate information from the survey. Upon executing a simulation, version 2 will calculate the beta distribution parameters for each resource type/control condition. A time, in minutes, will be stochastically generated from the appropriate beta distribution when each firefighting resource is dispatched, and the corresponding sustainable production rate for that resource will be calculated.

Fire Behavior Module

The most straightforward way to capture real-world variability in fire behavior in an initial attack simulation model is via a stochastic representation of forward rate of spread (ROS), since this single variable integrates both fuel and weather conditions. Together with a fire shape assumption (e.g., 2:1 ellipse), ROS determines a simulated fire's perimeter growth. This, along with the fireline production capability of the firefighting resources dispatched to the fire, can then be used to determine whether or not a simulated fire would be contained within specified simulation time and size limits.

Historical 2 p.m. "worst case" National Fire Danger Rating System ROS estimates are available for more than 200 AFFIRMS weather stations in California. Each fire record in the CDF's databases is now being augmented with the ROS estimate for the most representative weather station and fuel model. These ROS estimates permit preliminary estimation of ROS distributional parameters, by FDL and ranger unit. However,

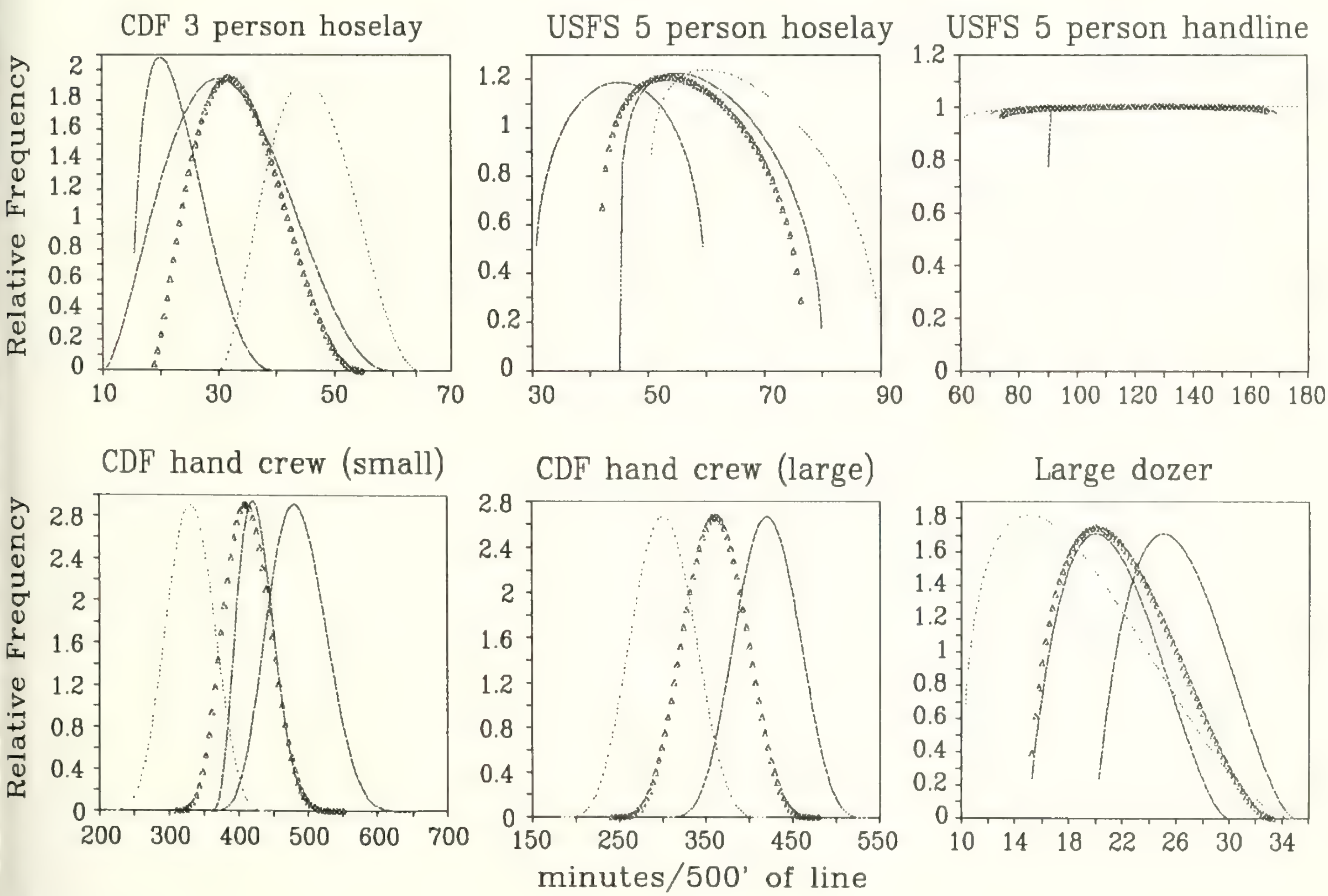

Figure 5.-- Beta distributions of the time required to complete 500 feet of fireline in brush fuels for six equipment/tactics combinations (distributions derived from individual estimates indicated by solid lines; from pooled estimates, by triangles).

final FMAZ specific parameter estimates will probably be derived from the set of all 2 p.m. ROS estimates from the representative weather station for days with a given FDL, thereby integrating additional years of available weather history. For simulation purposes, the characterization of a day in the fire season will be based upon either simple proportions or probit models. A separate study is now underway to assess the feasibility of adjusting 2 p.m. ROS estimates to reflect diurnal variation in fire behavior.

A potential weakness of this approach is that it would not reflect any correlation between fire multiplicity and variation in 2 p.m. ROS. We do not view this as a serious problem, since the strength of this correlation has not been established in the fire literature.

Conclusions

CFES-IAM version 2 will contain stochastic representations of wildfire occurrence, behavior, and initial attack control efforts. Estimation of the parameters of the distributions used to characterize these phenomena will be based upon ordinary local historical fire records. Experimental versions of the stochastic version 2 modules confirm the feasibility of micro-computer implementation of a more rigorous initial attack simulation model. Ultimately, providing local CDF decision-makers with a powerful analytical tool that they can master without extensive training may be of more value than the expected increases in the model's validity.

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Consideration of Risk in Forest Project Analyses

Eric L. Smith[1]

Abstract.--Risks are present in forest projects and should be considered in project analyses. Appropriate analysis techniques need to be matched to situations by considering physical and institutional factors. Various techniques have been applied to forest projects, but often only as research examples. Project planners need to not only measure risk, but also try to reduce or manage it.

Forest managers face uncertainty from many sources. When planning forest management projects and programs, these uncertainties must be considered to make choices among alternatives and to predict future forest outputs. The major sources of uncertainty are: (1) lack of information about resources and natural processes; (2) unpredictable changes in future demand for forest products; and (3) catastrophic natural events which can both damage resources and alter the natural environment. For the purposes of this discussion, I will define risk as being the variability which uncertainties cause in the desired forest management outputs.

Within the fields of operations research, business management, and economics, many analytical procedures have been developed to incorporate consideration of risk in decision making analyses. Many of these procedures are widely known to those conducting analyses of forest management projects, and there are many published examples of their application in forestry. However, procedures to calculate and consider risk in forest management project analyses are not included in many cases where significant risk exists. Furthermore, risk analysis techniques are sometimes poorly suited to the applications to which they are applied.

Dimensions of Risk

There are a variety of risk analysis procedures and a variety of situations in which they may be applied. If the analysis is to be useful and appropriate, it must be matched to the context in which the decision is being made. There are three major dimensions which should be considered. First is the nature of the uncertainties being faced and the degree to which they can be measured and translated to risk in outputs. This can be labelled the statistical dimension of risk. Second is the size of the risk relative to the size of the project and to the size of the program of the administrative unit carrying out the project. This is an economic dimension. Third is the complexity of the decision being made--is the project being evaluated on a single criterion or on multiple criteria? This is a policy dimension, involving trading off risk and levels of different kinds of alternative outputs.

Statistical Dimension

The primary quantitative concept in risk analysis is probability. In classical statistics, a statement of probability is interpreted as the distribution of outcomes over repeated trials or the theoretical distribution of outcomes. The probability established by sampling or experimentation serves as an estimate of "true" probability. Many natural resource management situations are a result of natural phenomena over large areas and long times. Insect epidemics are an example of such a phenomenon. Often such a set of circumstances is present in which various factors are known to have an effect on the outcome, but no adequate model or experimental results are available to predict the aggregate outcome of these circumstances. In these cases, the statement of probability takes on a Bayesian meaning--it is a statement of belief in the distribution of outcomes.

The two extremes of the statistical dimension could be labelled "unique" and "repeatable" situations. The significance of this dimension is the source and properties of the predictors of outcomes. In repeatable situations, one can seek experimental or empirical results with which to make predictions. Past results or sampling will allow precision estimates to be attached to predictions.

[1] *USDA Forest Service, Pacific Southwest Region, San Francisco, Calif.*

With unique situations, judgment and expertise, or "expert opinion," must be employed. Stochastic simulation models may also be useful, where outcome distributions are created based on probabilistic inputs. In using techniques such as decision analysis, elementary texts often advise employing "expert opinion" or perhaps the opinion of the "decision-maker" to provide probability estimates. Practitioners should be aware that psychological research in this area has shown that the quality of information obtained using this approach depends how the questions are asked (Fischoff 1984, Kahneman et al. 1982). Biases in estimates are likely without corrective procedures. Application of subjective assessments in forest protection models is discussed by Cleaves et al. (1987).

Economic Dimension

Those studying risk in the context of gambling have long known that the desirability of a bet varies both with the odds of winning as well as the size of the bet. It is the importance of the size of the bet, the amount at risk, which has introduced the concept of utility and risk preferences into risk analysis. A person who is willing to take a wager where the expected value of the payoff is equal to the amount wagered is defined as being risk neutral. However, an individual may be risk neutral when small amounts are involved, but risk averse (requiring an expected value greater than the amount bet) when larger amounts are involved. It has been stated by Arrow (1965) that a government should be risk neutral in its investment policy. This principle has been used to argue that public natural resource agencies should, in general, disregard the magnitude of risk in a decision and consider the expected value of the payoff.

Because the principle that marginal utility declines with increasing quantity can be applied to resource management, outputs at different levels can have different per unit value. Because many forest outputs do not have market values, establishing marginal values is difficult. In lieu of this approach, we can use the concept of risk adversity, particularly in the domain of losses, to substitute for establishing marginal values. A good example of such use would be for endangered species management. Here, a choice of two projects which could affect the population should probably be made on a risk-adverse basis, favoring the alternative with the least chance of a large loss. Risking an rare resource such as this is analogous to making a large wager and being wiped out on a single play.

The logic that risk adversity is an appropriate substitute for marginal valuation can be extended to other situations, to some extent. The larger the amount of assets which are involved, the more negative consequences are likely when losses occur. Catastrophic losses from fire or insects may cause regional economic impacts or negative river drainage impacts which would not be present with similar, but smaller, events.

The analyst must also be aware that the responsibility for making decisions for alternatives containing risk is likely shift up the organizational ladder as the resources at risk increase in value. If the relative magnitude of the risk is obscured by the analysis, the decision-maker may find himself or herself taking inappropriately large risks. There is an value of information aspect here as well. Large potential losses or large investments obviously merit more study, more data collection, and more carefully chosen analytical techniques. However, if similar small decisions are faced repeatedly, a fixed policy or specially designed heuristic decision process could be justified.

Policy Dimension

When more than one criterion is applied to a decision or when a project involves multiple objectives, a policy issue arises in how the criteria should be weighted. The simultaneous consideration of risk along with other variable creates a considerably complex analytical problem. Such situations are common in natural resource management, but are often approached in a way which ignores the complexity. Under such circumstances, it is usually the consideration of risk which is ignored. The use of linear programming for forest planning is a good example of this situation. Risk analyses involving tradeoffs between environmental health issues and costs often include both risk and multiple criteria consideration.

Just as the scale of the risk affects the level at which the decision is made, the multiple criteria situation calls for appropriate policy input. Techniques which rely on simple weighting schemes are not likely to capture the true preferences of the decision-maker when the criteria are applied to specific choices. Even worse are procedures which implicitly assume these tradeoffs. On the other hand, displaying too much information or too many choices can overwhelm the decision-maker. One partial solution to this situation is the use of stochastic dominance techniques (Buckley 1986). This approach winnows out clearly inferior alternatives and identifies the differences among those remaining. It has been used in evaluating spruce budworm management policies (Thompson et al. 1979).

Areas of Application

The dimensions of risk considerations outlined above include both the need to consider the nature of the problem and the institutional environment of the decision when selecting and applying an analytical technique. What follows are examples of applications of risk analysis for forestry projects and planning.

Variable Discount Rates

The use of variable discount rates to adjust for the riskiness of projects is a form of risk analysis when two or more economic returns are being compared. This approach is intuitively logical and follows common business practice, where the customers

who are considered most credit-worthy or who are borrowing for less risk-prone purposes pay lower interest rates. Foster (1979) gave a simple illustration of this approach in a forestry context. Chang (1980) commented that this approach would give biased results if one had a declining marginal utility for the income produced, and that a constant rate applied to the expected value of the utility of the outcomes was a better approach.

Reed (1984) showed mathematically that a time-independent constant probability of total forest destruction has the same effect on the optimal rotation length Faustmann formula results as adding that probability to the discount rate. When the probability of destruction changes over time, the results are also effected by the reestablishment costs.

This approach is not useful when considerations such as salvage values are included. These discussions do serve to emphasize the existence of risk, however. It does seem useful to define the risk inherent in forestry projects in terms of discount rates as a first step, given that many analyses neither adjust rates for risk nor consider anything but an optimistic outcome.

Hertz-Thomas Method

Using a variable discount rate to express risk can only adjust the average return on the investment, and can only be easily used when outcome probabilities are simply expressed. A method of more completely displaying the effect of uncertainty on returns has been developed by Hertz and Thomas (1983). The method uses computerized Monte Carlo simulation to construct a probability density function of financial returns. The use of such a simulation technique allows the simultaneous consideration of several stochastic variables. It also has the advantage of displaying the probabilities of the entire range of outcomes. This allows the decision-maker to use whatever risk criteria he deems appropriate in evaluating the risk. The method is similar to sensitivity analysis, but superior, since the simulation model can handle variations in conditions simultaneously, which is important when variables are correlated.

Recent applications in forestry include an analysis of risk of insect attack in plantation investments (Anderson et al. 1987), and a similar analysis of plantation investments which incorporated variable future prices, costs, and yields (Lothner et al. 1986). The former displayed outcomes as a cumulative probability distribution of internal rates of return, while the latter used relative frequencies of net present value.

Decision Trees

The classical approach to making decisions under risk is by the use of decision trees. This represents the decision process as a series of decisions and probabilistic states of nature, making decision choices based on maximizing the expected values of probability distributions. The basic weakness of the method is that it does not allow for the tradeoff to be made between maximizing expected value and decreasing risk. Also, the problems of accurately assessing subjective probabilities are critical here.

Several applications of decision trees have been made in forest protection. In fire management, they have been used for both wildfire situations (Seaver et al. 1983) and for prescribed fires (Cohan et al. 1984). It is particularly important in wildfire situations that some conscious decision be made as to the tradeoff between minimizing the expected total fire costs and reducing the potential for very large fires. Normal use of decision trees will not provide guidance on this tradeoff. Talerico et al. (1978) have demonstrated the use of decision trees in a pest management context.

Risk in Planning and Harvest Scheduling

The use of linear programming models for forest planning and harvest scheduling has made the incorporation of risk consideration in these activities difficult. Models such as FORPLAN, used in National Forest planning, are already large and costly to run without the added complexity that risk consideration would add. Nonetheless, it is recognized that uncertainty exists in forest productivity, future output values, and future costs. Allowance for risk of reduced outputs are sometimes made by decreasing production rates for timber stands, reflecting average rates of damage from fire, pests, or other factors.

The effects of uncertainty and variation on linear programming models for forest planning applications has been analyzed by other authors (Hof et al. 1988, Pickens and Dress 1988) and summarized elsewhere in these proceedings by Pickens and Hof. These studies show that even without the uncertainties of catastrophic evens, expected value production estimates of stochastic variables can result in biased and infeasible solutions.

The effect considering pest epidemics could have on National Forest plans has been shown by a study involving tussock moth outbreaks on two National Forests (Forest Pest Management 1984). This study estimated the reduction in net present value which is likely to occur due to periodic tussock moth outbreaks, and the efficiency of two different spray treatments. The study created a random series of outbreaks based on historic frequencies, and factored the damage into production rates within a FORPLAN model. It was shown that both spray programs would have positive returns.

The tussock moth study approach, while showing for one Forest an almost 30% decrease in the expected present net value when the probable damage was considered, underestimates likely losses. By creating an optimal harvest schedule given a sequence of moth outbreaks, the model can arrange harvests and treatments knowing when future outbreaks will occur. The real occurrence of outbreaks would certainly be different than the randomly generated one used in the simulation. Therefore, the true optimal solution would also be different. Since a different optimal solution for a different outbreak sequence would be

expected to yield, on average, a net present value the same as in the modeled solution, the modeled schedule would likely yield a lower net present value for the different outbreak sequence.

Hoganson and Rose (1986) applied their innovative harvest scheduling solution technique (1984) to determine the risk effects of price uncertainty on a harvest scheduling problem. They emphasized the differences in the first period decisions, showing which subset of the stands would be treated differently given different future prices. Their logic is that as prices change in the future, new harvest schedules will be constructed. It is only the near term decisions which need to be made without the benefit of knowing some future prices. A similar approach could be applied to supply uncertainties involving fires or pests.

Risk Reduction and Management

Measuring risk and making decisions while considering risk is not all that can be done. Risk can be reduced and managed. The first step is to recognize the amount and sources of risk. As discussed above, "experts" are not necessarily able to accurately judge the probability of events. In fact, they generally predict too narrow of a range of possible outcomes and are too confident of their predictions.

Some risk is caused by uncertainties which could be reduced with additional information. "Value of information" analyses are well known to those familiar with operations research, but they are rarely applied to forestry problems. Many kinds uncertainties exist which cannot be resolved by data gathering, however, and they must be dealt with in other ways. One possible approach is planned diversification. In business, one such approach is portfolio management. The idea is to take actions which have risks which are negatively correlated to each other, or at least independent of each other. This has been considered in forestry in the context of financial uncertainties, but not, to my knowledge, in the context of biological or technological uncertainties.

Finally, we need to view some uncertainties and the risks they cause as being inevitable, and view our projects and plans as being temporary and subject to change and modification. Projects which are flexible or sound under a range of future conditions have an unmeasured benefit when judged under a single set of assumptions about the future.

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Identifying Sort Yard Locations With Size Dependent Processing Costs

John Sessions, John J. Garland, and Gonzalo Paredes[1]

Abstract.--Sort yards placed at selected intermediate points between timber cutting sites and mills have the potential for increasing the value of logs or trees destined for processing into different products. A two-phase modeling procedure is presented for identifying the efficient placement of sort yards using computations much simpler than those in standard linear mixed-integer programming methods.

In forest operations, the decision of how to transport trees from the stump to the manufacturing destination must consider: cost and effort of transporting the logs or trees to roadside, the relative efficiency of bucking in the woods or on the landing, legal restrictions on log or tree transportation, distance to mills, and the prices paid for logs or trees at their final destinations. An important alternative to consider is the construction of sort yards.

Sort Yard Functions

Sort yards, wood yards, log storage yards, mill yards, satellite sort yards, and dryland sort yards describe the location and set of activities related to materials handling at intermediate points between the landing (used for yarding and loading) and the point where these materials enter the mill or where they are transshipped to other locations, e.g., dockside for export, sale to another purchaser, etc. Sort yards may be located adjacent to a mill or transshipment point, or they may be at a central point nearer the woods operation some distance from processing plants.

Typically sort yards perform a variety of vital functions for a forest products firm. The majority or all of the functions listed below are performed at sort yards:

- A facility to separate and aggregate materials according to species, grades, sizes, and user requirements.
- A facility to measure materials for transactions, e.g., scaling, weight measurement, for payment.
- A location to store and inventory materials.
- A facility to upgrade and remanufacture materials for users.
- A product showplace, e.g., a place for export or other purchasers to review materials.
- A conversion facility, e.g., logs, chunks into chips via a portable chipper, or chunks into shake bolts.
- A significant generator of debris and waste material.
- A transportation hub for truck/rail/water transshipment, e.g., to quickly free log trucks for return to woods operations.

A sort yard may be most analogous to warehouse activities of general manufacturing except the materials handled may be trees, logs, poles, chips, shake or shingle bolts, or even firewood.

Locating Sort Yards

Forest products firms can analyze their choices for sort yards by considering the costs of construction, processing costs, the increased value of products processed in a sort yard, and various costs in a transportation network. Ideally, firms would like to know which sort yards to build to accommodate various sources of timber supply. Analysis procedures should also identify which sources should bypass sort yards as well and move directly to mills or other end points.

Analysis procedures may include various techniques that treat the fixed investment of constructing the sort yard. Sessions

[1]*Associate Professor, Timber Harvesting Extension Specialist, and Graduate Research Assistant, College of Forestry, Oregon State University, Corvallis, OR.*

and Paredes (1987) describe a two-phase modeling method that solves the sort yard location problem with a given processing cost for each sort yard.

Size-Dependent Processing Costs

The two-phase modeling approach is modified here to account for processing costs which vary as a function of piece size. Most materials handling techniques in sort yards are piece-by-piece operations. Handling larger pieces reduces the cost per unit volume of sort yard processing. More significantly, handling small pieces (logs) in a sort yard is costly and should only be undertaken if value increases exceed the processing costs.

Each sort yard might have its own processing cost function that varies by piece size, but often the materials handling equipment is similar so a processing cost function of the type shown in figure 1 might be expected (Garland 1983). A simplified version of this cost function is used in subsequent examples to illustrate solution procedures for sawlogs and pulpwood.

Proportions of Piece-Sizes

Each log size has a unique processing cost through a sort yard. For computational purposes, however, we categorize loads of trees or logs arriving at a sort yard as belonging to a "proportion." For example, one proportion might be 40% small, 30% medium, and 30% large logs. We might categorize wood arriving from each of 100 operations as belonging to one of 25 proportions. The various sources may have a mix of proportions that approach normal, exponential, uniform, or other distributions of piece sizes depending on timber characteristics.

As we will see, the size of the problem rapidly increases with the number of proportions to be considered. Although using more realistic sort yard processing costs accurately portrays the value difference of gains over costs, we will need to achieve a compromise.

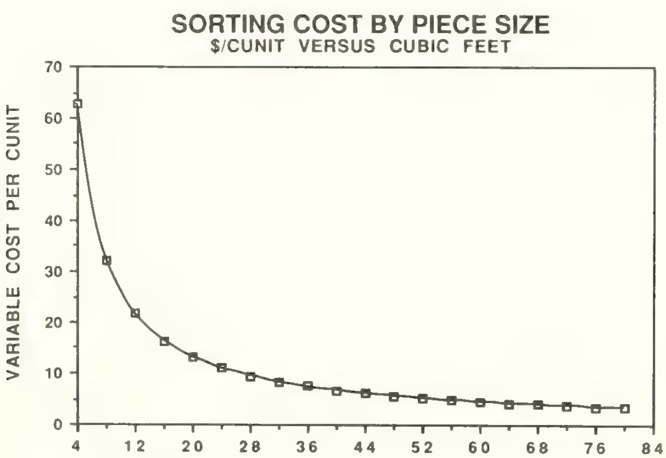

Figure 1.--Sorting costs ($/cunit) by piece size (cubic feet).

Modeling and Solution Approach

The construction of sort yards can involve considerable investment. The decision to construct the sort yard must include the cost of construction and operation, the increased value of wood that is achieved through improved cutting and sorting of logs in a more controlled environment, the ability to allocate parts of trees to alternative destinations, and the transportation cost of the various products over the transportation network.

Because of the fixed investment in a sort yard, the problem structure results in a linear mixed-integer programming problem. Problems involving even a small number of alternative sort yard locations tax the computational capabilities of current mixed-integer programming algorithms. We shall demonstrate a two-phase procedure for solving the sort yard location problem which overcomes the computational complexities of conventional linear mixed-integer programming approaches.

The solution strategy exploits the network structure of the problem. Two related shortest-path subproblems can be easily identified: one dealing with the path *from* the point of potential sort yard locations *to* the final destinations, and the other with the path *from* the point of harvest *to* the potential sort yard locations. We will first solve the shortest-path problem from the potential sort yard locations to the final destinations, and then combine these results with the original problem to solve a mathematical problem that is much simpler than the original problem. We explain below how destinations are defined here.

In the first phase we solve for the shortest path from all possible sort yard locations to destinations. This is normally a value-maximization problem in which both costs and revenues are considered. Costs are associated with the transport operations. Revenues correspond to the different prices at which mills purchase each commodity. Since commodities are not homogeneous, we add a "super" destination node for each commodity type. The mills purchasing a commodity are then connected by an arc to the corresponding super destination node. The cost coefficient of these arcs equals the negative of the per-unit price the mill offers for the commodity. This phase can be readily solved as a linear programming problem without any integer variables, or as a shortest-path network problem using any of a number of algorithms summarized by Smith (1982).

The results from the first phase (minimum-cost or maximum-revenue paths) from candidate locations to destination nodes, and the discrete location variables (with their associated fixed costs) are included, in the network for unsorted commodities, as additional arcs. For each candidate location there is one additional arc to each super destination. The original problem is now reduced to a shortest-path problem from timber sources to super destinations, with fixed costs represented in some of its arcs.

For problems involving less than approximately 50 candidate locations, this second phase can be solved as a conventional linear mixed-integer mathematical programming problem, with the integer variables being the location options. For larger problems, the second phase can be solved using any of a

number of heuristic procedures. Steinberg (1970) has demonstrated that for the facilities location problem, heuristics have satisfactory accuracy and require less computation time than the branch-and-bound algorithm commonly used to solve the mixed-integer linear mathematical programming problem. In the examples that follow we chose to use the heuristic implemented by Sessions (1987) to solve the second phase because it includes the explicit identification of optimal transport routes. This heuristic is based upon a procedure developed by Cooper and Drebes (1967) using a shortest-path labeling algorithm similar to that developed by Dijkstra (1959). Regardless, however, of the method chosen for solving the second phase, the two-phase modeling procedure is much simpler to formulate and solve than the conventional mixed-integer linear programming approach, because it involves much fewer equations.

The two-phase modeling method can be extended to encompass processing of logs or trees at the stump or at roadside, increasing the number of products provided at the sort yard, adding flow constraints on the sort yards, and analyzing over multiple periods. Construction of roads to alternative standards can also be considered if the roads are on the periphery of the network.

Example

Assume that the road network is as shown in figure 2. Sources are at nodes 1, 2, 3, and 4, with volumes and proportions of pulpwood and sawtimber given in table 1. There are two mills. One mill is at node 7 and the other mill is at node 8. The mills will pay according to the schedule in table 2 for delivered wood. The cost of transporting mixed wood, pulpwood, and sawtimber is given in table 3. Further assume that a sort yard could be built at any node except nodes 7 or 8. The cost to build a sort yard at any node is given in table 4. The cost for processing wood in the sort yard is $6 per cunit for pulpwood and $2 per cunit for sawtimber. If mixed wood is delivered to a mill, the delivered mill price is the weighted value of the pulpwood and sawtimber prices, less the penalty given in table 2. The objective now is to decide whether sort yards should be built, where and over which routes wood should be transported, and to which mills it should be routed.

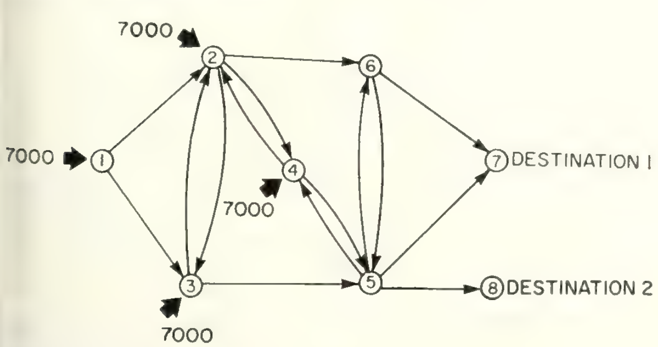

Figure 2.--Network showing four entry points and two destinations.

Table 1.--Wood sources and proportions of pulpwood and sawtimber.

Node	Volume *cunits*	Pulpwood %	Sawtimber %
1	7,000	30	70
2	7,000	50	50
3	7,000	30	70
4	7,000	50	50

Table 2.--Prices mills will pay for delivered wood.

Node	Pulpwood $/cunit	Sawtimber $/cunit	Mixed wood penalty $/cunit
7	40	100	5
8	50	90	5

Table 3.--Unit costs for wood transport for alternative products.

Link from	Link to	Mixed wood *$/cunit*	Pulpwood *$/cunit*	Sawtimber *$/cunit*
1	2	1.0	0.8	0.9
1	3	2.0	1.6	1.8
2	3	2.0	1.6	1.8
3	2	4.0	3.2	3.6
2	4	3.0	2.4	2.7
4	2	2.0	1.6	1.8
4	5	5.0	4.0	4.5
5	4	4.0	3.2	3.6
5	6	3.0	2.4	2.7
6	5	5.0	4.0	4.5
2	6	6.0	4.8	5.4
6	7	7.0	5.6	6.3
5	7	5.0	4.0	4.5
3	5	3.0	2.4	2.7
5	8	6.0	4.8	5.4

Table 4.--Initial investment required to build sort yard.

Location *(node)*	Initial investment *($)*
1	40,000
2	50,000
3	40,000
4	55,000
5	32,000
6	33,000

The problem is solved in two phases. In the first phase the shortest path (the one that yields the lowest transport cost for the sorted wood for pulpwood and sawtimber) is determined from each candidate sort yard location to the mill. The shortest path includes the choice of mill. This is done by linking the mill destinations together and adding a "super destination" at node 9 for pulpwood and another "super destination" at node 10 for sawtimber (fig. 3). The links joining the actual mills to the super destinations have a negative variable cost equal to the delivered prices the mills would pay for the respective products.

One unit of volume is now sent from each candidate sort yard location to each super destination, using the appropriate set of transport costs. In other words, the pulpwood transport costs are used when the wood is transported to the pulpwood super destination, and the sawtimber transport costs are used when wood is transported to the sawtimber super destination. The path that this volume takes will indicate which mill will be the destination (table 5).

Table 5.-- Shortest paths and costs for transportation of one unit of wood from each candidate sort yard node to the mill. Negative costs are transport costs minus mill delivered prices.

Node	Path	Mill	Pulpwood cost $/cunit	Sawtimber cost $/cunit
1	1-3-5-8-9	8	-41.20	--
2	2-3-5-8-9	8	-41.20	--
3	3-5-8-9	8	-42.80	--
4	4-5-8-9	8	-41.20	--
5	5-8-9	8	-45.20	--
6	6-5-8-9	8	-41.20	--
1	1-3-5-7-10	7	--	-91.00
2	2-3-5-7-10	7	--	-91.00
3	3-5-7-10	7	--	-92.80
4	4-5-7-10	7	--	-91.00
5	5-7-10	7	--	-95.50
6	6-7-10	7	--	-93.70

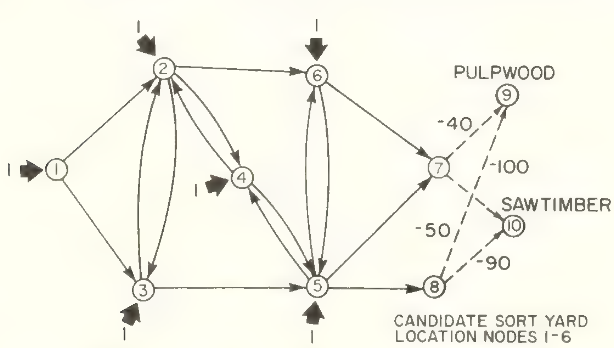

Figure 3.--Network for phase 1 used to derive least cost path for one cunit of sawtimber and one cunit for pulpwood from each candidate sort yard location to the final destination for the respective product. The negative values indicate the delivered price each mill would pay for sawtimber and pulpwood.

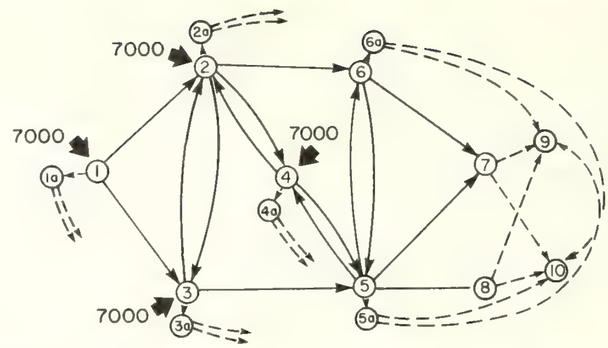

Figure 4.--Expanded network for phase 2 showing added arcs from each candidate sort yard location to super destinations. Node 9 is the super destination for proportion j = 50/50 and node 10 is the super destination for proportion j = 30/70.

In phase 2, one "super destination" node is added for each proportion. Since we have two proportions in this problem, there will be two super destinations. Then one sort yard "investment node" (node 1a, 2a, 3a...etc., fig. 4) is appended to each candidate sort yard node and from this node two links are added to the network. The link from the candidate sort yard node to the "investment node" has a fixed cost and zero variable cost. The fixed cost equals the sort yard investment cost. The two links from the investment node to the super destinations use the information from phase 1. The descriptors for these links are a zero fixed cost and a variable cost. The variable cost is given by equation [1].

$$VC_{ij} = P_{pj}\,[HC_{pi} + SC_p - V_p] + P_{sj}\,[HC_{si} + SC_s - V_s] \qquad [1]$$

where:

VC_{ij} = the total weighted unit cost for transport of one cunit of proportion mix j from node i to the mill,

P_{pj} = the proportion mix j for pulpwood,

P_{sj} = the proportion mix j of sawtimber,

HC_{pi} = the transport cost per cunit over the least-cost route from node i to mill for pulpwood,

HC_{si} = the transport cost per cunit over the least-cost route from node i to the mill for sawtimber,

SC_p = the sorting cost per cunit for pulpwood,

SC_s = the sorting cost per cunit for sawtimber,

V_p = the delivered mill price per cunit for pulpwood,

V_s = the delivered mill price per cunit for sawtimber.

The expanded network for phase 2 is shown in table 6 and figure 4. In phase 2, the nodes 9 and 10 are super destinations. Now, however, node 9 is the super destination for all source

Table 6.-- The link data for the expanded network. Negative costs are variable costs minus mill delivered prices.

Link from	Link to	Variable cost ($/cunit)	Fixed cost ($)
1	2	1.0	0.0
1	3	2.0	0.0
2	3	2.0	0.0
3	2	4.0	0.0
2	4	3.0	0.0
4	2	2.0	0.0
4	5	5.0	0.0
5	4	4.0	0.0
5	6	3.0	0.0
6	5	5.0	0.0
2	6	6.0	0.0
6	7	7.0	0.0
5	7	5.0	0.0
3	5	3.0	0.0
5	8	3.0	0.0
1	1a	0.0	40,000.0
2	2a	0.0	50,000.0
3	3a	0.0	40,000.0
4	4a	0.0	55,000.0
5	5a	0.0	32,000.0
6	6a	0.0	33,000.0
1a	9	-62.10	0.0
2a	9	-62.10	0.0
3a	9	-63.80	0.0
4a	9	-62.10	0.0
5a	9	-66.35	0.0
6a	9	-63.45	0.0
1a	10	-74.48	0.0
2a	10	-74.48	0.0
3a	10	-76.22	0.0
4a	10	-74.48	0.0
5a	10	-78.83	0.0
6a	10	-76.37	0.0
7	9	-65.00	0.0
8	9	-65.00	0.0
7	10	-77.00	0.0
8	10	-73.00	0.0

with the proportion mix j = 50/50, and node 10 is the destination for all sources with the proportion mix j = 30/70. In other words, there will be one super destination for each proportion; at most n super destinations if there are n proportions. The network for phase 2 is now complete. The solution to this network can now be obtained using mixed integer programming or heuristics. The solution for phase 2 is shown in table 7. One sort yard should be built at node 5 and wood from all source nodes should be delivered to the yard for intermediate processing. The information from phase 1 (table 5) is used to indicate the route and destination for the pulpwood and sawtimber when it leaves the sort yard. Pulpwood leaving the sort yard should go to the mill at node 8; sawtimber should go to the mill at node 7 (fig. 5).

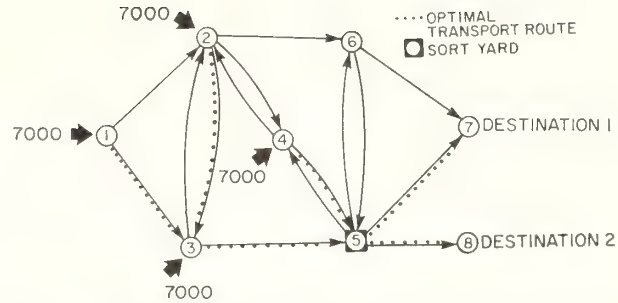

Figure 5.–Network showing transport routes with sort yard constructed at node 5.

Discussion

Using the two-phase modeling approach one can quickly identify the size of the network for each phase. For phase 1 the network size will be approximately the size of the original network plus dummy links to represent prices. For phase 2 the network size is primarily determined by the number of sort yards and the number of proportions. The phase 2 network will be approximately equal to the original network *plus* the sort yard investment links *plus* the product of the number of sort yards multiplied by the number of proportions. In other words a 1,000 link road network with 50 sort yard locations and timber arrivals categorized by 50 proportions would require approximately 1,000 + 50 + (50)(50) or 3,550 links.

Another variation of the sort-yard problem solves the operational question of which "proportions" should pass through a previously constructed sort yard. Once the initial problem of locating and constructing sort yards has been solved, the "investment" cost has occurred and the allocation of various proportions through sort yards or to final destinations is a significant operational concern.

A similar two-phase solution procedure without investment costs for the sort yard, but with sorting costs by piece size included, yields which proportions from various sources would gain in value over the returns from sending them to final destinations without sorting. The time frame from an operational standpoint would require using the model whenever the

Table 7.-- Solution for Phase 2. Negative costs are interpreted as positive profit since problem is being solved as cost minimization.

Node	Volume	Path
1	7,000	1-3-5-5a-10
2	7,000	2-3-5-5a-9
3	7,000	3-5-5a-10
4	7,000	4-5-5a-9

variable cost - $1,906,520
fixed cost $ 32,000
total - $1,874,520

"proportions" changed from sources, whenever relevant costs changed, or whenever product returns changed.

Regardless of the size or management, there is some limit to the number of pieces per unit time (day, shift, etc.) that sort yards can handle. Often, before the absolute limit is reached, sort yard managers use overtime resources or add more equipment to handle increases. These management practices may be modeled as alternative cost functions for the sort yard once certain limits are reached. The cost function might be shifted upwards to reflect overtime costs or it may be higher as well as change shape as additional equipment is added.

One way to model capacity limits is to expand the phase 2 network by including a capacity link between the investment node and the "proportions" node for each cost level. For three levels of costs (straight-time, overtime, and additional equipment), three capacity links would be needed and the number of arcs added to the network would be tripled. This formulation would be useful for operational planning to balance surges in production.

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A Systems Analysis Approach to Economic Feasibility Analysis for Forest Products Utilization

Thomas C. Marcin[1]

Abstract.--Systems analysis is often used in developing forest management plans and policies. This paper presents a conceptual framework for the systematic evaluation of forest product utilization technology in the context of the forest resource system. Emphasis is placed upon evaluating the economic feasibility of forest product utilization as a component of the forest resource management system.

This is a conceptual paper rather than a procedural paper. An expanded view of systems analysis is presented in an attempt to broaden thinking about what feasibility analysis means and how evaluation of forest products utilization might be improved--which is what system analysis is all about. The generalized view of systems analysis has been expressed by Casti (1987) as follows:

problems + tools + a world view = insight

Casti explains that an indispensable role is played by one's scientific *Weltanschauung* or "world view" in determining the nature and degree of insight that can be gained about any problem. When translating a problem statement into a formal mathematical structure, the world view is represented by the type of formal mathematical system chosen to reflect the features of the problem. In turn, this mathematical world view dictates the questions that can be asked and the tools and techniques that can be used to seek insights and answers (fig. 1). Furthermore, I will explain that a formal mathematical model is not required in every case and that judgment and extra rational variables can be considered because systems analysis is usually a mixture of qualitative and quantitative analysis.

The primary purpose of this paper is to recognize that forest product utilization and forest resource management are inexplicably intertwined in the forest resource system. The forest resource system, a set of interacting variables, is part of a larger system that is the sum of human experience and defines the value of forest resources (Duerr et al. 1979). It is obvious that in order to manage forests economically, timber and other biomass removals must be converted into products that are marketable at a price higher than the cost of producing the products. To accomplish this, the removals generally go through some type of conversion process. This paper attempts to provide a conceptual basis for the development of these broad concepts. I begin by providing a discussion of general system concepts and methodology. Then, I present a conceptual application to the forestry sector.

System Analysis Concepts

There are probably as many definitions of systems analysis as there are systems analysts. The systems analysis concept presented here departs from previous system analysis literature in that a mathematical systems model does not have to be the central component of the problem solution. The central component of analysis may be quantitative, qualitative, or mixed, and it may be an expert person or a computer information system.

Methodological tools considered for systems analysis range from behavioral research into what exists, through values research into what is preferred, to normative research into what should be. Research efforts to demonstrate the three fundamental components of feasibility analysis--economic, technical, and socio-political--are difficult and ephemeral, either taken individually or considered together. Krone (1980) provides a statement of general system concepts that also reflects my view:

[1] *Economist, USDA Forest Service, Forest Products Laboratory, Madison, WI. The Forest Products Laboratory is maintained at Madison, WI, in cooperation with the University of Wisconsin.*

"A system is defined as a set of interacting elements. The systems approach provides understanding and comparisons within and between systems. Systems analysis is a set of techniques that are qualitative, quantitative, and mixed-deriving methodologies from the scientific method, systems philosophy, and branches of various scientific disciplines dealing with the phenomenon of choice. Systems analysis incorporates both explanatory and prescriptive methodologies."

A system is a collection or arrangement of entities or things related or connected such that they form a unity or whole. Some entities are retained in the system or are endogenous, while others are transient to it. Transient entities are generally input to the system and undergo some conversion process and, subsequently, output from the system. During the time they are in the system, they are part of the system. However, before and after they are in the system, they are external. Anything external is referred to as the system environment (Wetherbe 1984). The major benchmarks of the performance of a system are improvement of the quality of a system as evaluated and measured against standards consciously selected, and the feasibility and desirability of improvement or redesign possibilities. Systems analysis is a major instrument for this purpose.

Conceptualizing appropriate analysis models for complex problems is an essential macro tool of the systems analyst. This section provides conceptualization and structure for the identification and management of knowledge prerequisites for technology and transfer. The knowledge for systems applications can be classified into the following three categories:

1. *Environmental knowledge* is about the understanding, control, and direction of the environment. This knowledge falls predominantly into the physical and natural sciences.

2. *Human knowledge* is about the understanding, control, and direction of individuals, groups, and society. This knowledge falls predominantly into the social, behavioral, and life sciences.

3. *Control knowledge* is about the use and further development of knowledge within the first two categories.

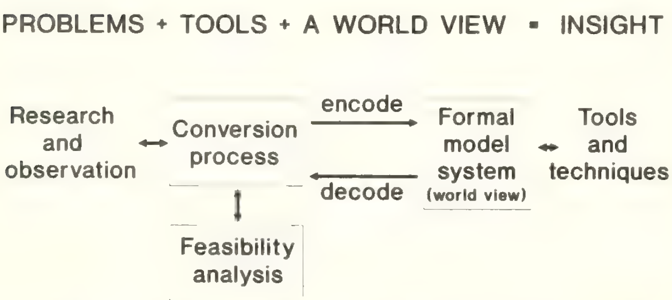

Figure 1.--The systems view as related to formal mathematical structure.

Knowledge is defined as tacit or explicit. Tacit knowled is obtained through living and is unformulated, personal, exp riential, nonexplicated, and involves the Gestalt process. It basic to human understanding, knowledge, and as a predom nate determinate of culture for the transmittal of knowled from one generation to the next. Expert knowledge is a comb nation of explicit and implicit knowledge. It is the extra ratio component of culture that is represented by emotion, prejudi and societal attitudes. Explicit knowledge is obtained throu learning and is articulate, public, objective, logical, and for the basis for the disciplines of learning. The articulate fram work for culture displays facts in words, symbols, formu maps, and other technical methods of expression.

Scientific knowledge is viewed by Kuhn (1962) as growi within normal science through the aggregation of informati consistent with a theory or replacement of one theory wit successor theory. He describes the process where normal s ence develops a paradigm or a universally recognized a accepted body of knowledge. This paradigm, for a time, pr vides solutions to problems for a community of scholars practitioners. Over a period of time, research and practic begin to reveal anomalous facts unaccounted for in the theo This stimulates new scientific discoveries and creates a crisis credibility in the paradigm. A new theory emerges that preci tates a scientific revolution or a nonaccumulative developme tal episode in which an older paradigm is replaced in whole in part by an incomplete new one, often with traumatic a long-range impacts on science, or scientists, and on socie Ample historical evidence in the physical sciences valida this theory. Reflections upon social sciences and the arts a reveal interesting insights when viewed through Kuhn theo (Krone 1980).

The scientific method where human systems knowledge increased, generated, applied, and analyzed, is diagrammed Krone as shown in figure 2. It has its conceptual beginning in prevailing scientific paradigm where the Kuhnian process be transformed by the process itself. The process of scienti knowledge accumulation is more complicated than this simp fied diagram, but the essential features are there. An import key to this approach is the evaluation and verification fo particular problem-orientated systems analysis by real wo performance over time. This macro validation process is imp tant to avoid closed and tautological systems for scien management organizations, and problem-orientated systems major distinction between the scientific method in syste science and the pure scientific method is the inclusion of decision maker. At some point in a real world system a decis on policy or action must be made. It may be based on scienti considerations or upon other considerations. In this case, i that of making feasibility analysis in the context of the ove forest resource system. The task here is to bring together the b scientific information in a systematic fashion and to presen for evaluation. The system concepts in this paper fall into category of research and analysis in the center of figure 2.

Quantitative Tools for Systems Analysis

Quantitative measurements allow us to organize knowledge, to compare results over time and space, to use mathematical methods to test hypotheses derived from scientific theory, to optimize system performance based upon alternative criteria, and to simulate present and future system output. It allows aggregation and manipulation of data in management information systems using more powerful and accessible computers.

Quantification allows reduction of the complexity to understandable levels for making decisions. It provides justification for stipulated system output. Through quantification we record events for later review, evaluation, comparison, and validation within the scientific method. We can design feedback mechanism for control and decision making by quantifying reports, relationships, and events over time. Simulation is possible with quantification. This requires a structured, rational, and repeatable process, capable of sensitivity analysis by adjusting quantitative independent variables for analysis of alternative outcome arrays. Useful relationships can be observed through mathematical and statistically derived transfer functions. Quantification is necessary, although it is not sufficient to measure the efficiency, effectiveness, and quality of the systems. Systems analysis is impossible without some degree of quantification. The ability to abstract the physical and social world into quantifiable models has been a major contributor to scientific, technological, and social progress. In summary, we must quantify to understand or improve human systems.

An important aspect of the success of a modeling effort is the choice of the correct mathematical structure to represent the system under study. This surrogate system must be representative of the "real system" and of the problems to be solved by decision makers or managers in a realistic manner. It is convenient to represent the set of mathematical paradigms into four principal components (Casti 1987). These categories are operations research (OR), computer science (CS), control theory (CT), and systems theory (ST). These specific techniques can be further classified as deterministic or stochastic.

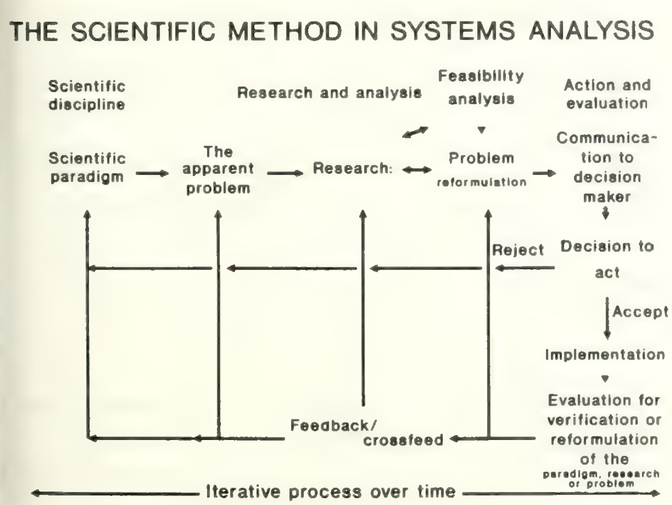

Figure 2.–The scientific method in system analysis as diagrammed by Krone (1980).

Operations research problems generally revolve around issues of planning, scheduling, and resource allocation. Methodologically, the techniques used are traditional OR tools: resource allocation, scheduling theory, inventory control, and decision analysis. Control theory, derived from aerospace and mechanical engineering problems in the 1960's, contains the concepts of system feedback, adaptive change, uncertainty, and complex hierarchy. Computer science has developed operating systems and new computer languages to be used to manage information and in conjunction with artificial intelligence or expert system techniques. These systems can also be used with OR or CT methods. Generally speaking, these models or tools are techniques of OR, CT, and CS. They start with a particular formal structure as listed in table 1 and analysts try to adapt problems to them. The basic problem revolves around how various applications can be addressed within the selected paradigm or technique.

System theory, on the other hand, differs in an important way from conventional operations research or management science methods. A systems theory world view focuses more upon paradigm construction than upon techniques and algorithms associated with a given framework. You start with the framework or point of view and explore how important concepts or issues might be addressed. The object of the systems view is to develop a set of techniques or paradigms that meet the objects of the system that may include some of the quantitative tools or methods in table 1. For example, Casti (1987) begins with the concepts of complexity, flexibility, self-repair, adaptability, self-regulation, reliability, resilience, and performance in his definition of the manufacturing process as a system. He then looks for an appropriate paradigm for the manufacturing system in a relational rather than structured way.

The indiscriminate and inappropriate use of quantitative tools has been greatly aided by the plethora of computer software that simplifies applying without necessarily implanting any understanding of underlying theoretical principles. As Wetherbe (1984) states:

> "First it is important to understand the difference between theory and technique. Theory is really nothing more then the notion or ideas about how things work or the way things are. Techniques are just different methods or approaches to perform different tasks. Ideally techniques should be based upon theory...Someone who knows technique without theory is potentially a dangerous person...Anytime someone uses a particular technique without knowing the reason for the theory behind it, that person is apt to use the technique when it is inappropriate."

A common criticism of the educational process is that it tends to teach students how to do exercises rather than how to solve problems. For example, we teach students how to write a computer program, how to solve a mathematical equation, or

Table 1.--Quantitative models and techniques in systems analysis. Source: Krone (1980) and author's interpretation.

Model or technique	Application	Knowledge base
	Deterministic models	
Linear programming	Allocation, distribution, and optimization in business, transportation, inventory, construction,logistics, and networks	Computer science, sensitivity analysis, algebraic solutions simplex tableau, and economics
Queuing theory	Waiting, services ratios and people, things, events	Monte Carlo, simulation, and statistics
Program management techniques	Production and construction planning	PERT (cost or time) GANTT charts, network analysis (CPM), and decision trees
Markov analysis economics	Marketing, sales, forecasting	Matrix algebra and economics
Conflict analysis	Business and psychology	Game theory
Quality assurance	Industry, defense	Technology and science
Cost/benefit	Resource allocation	Economics and statistics
	Probabilistic Models	
Dynamic programming	Multistage decision in production, allocation	Computer science and probability theory
Computer simulation	Systems interactions	Computer science and Monte Carlo
Probabilistic inventory models	Where demand and/or lead time are random	Probability theory and expected value statistics
Stochastic models	Computing probabilities of systems transition	Matrix algebra and calculus
Sampling, regression, and exponential smoothing	Problem solving with large populations	Statistics and probability theory
Bayes theorem	Forecasting under conditional probability and dependence, causal analysis	Algebra, probability theory, and knowledge of prior probabilities
Cost and benefit analysis	Resource allocation	Economics and statistics
Fault tree analysis	Systems behavior	Algebra and statistics
Artificial intelligence and expert system	Systems management	Computer science and cognitive science

[1]*Models that are applicable to problems where there is only one state of the world assumed and where variables, constraints, and alternatives are, after acceptable assumptions, known, definable, finite, and predictable with statistical confidence.*

how to do a financial analysis. The students, however, often do not know when it is appropriate to apply these techniques. This is similar to the story of the student who is taught how to use a screwdriver--the screwdriver being symbolic of a technique such as computer programming, linear programming, or net-present-value analysis. Upon being employed, the student is excited about applying the screwdriver to screws that need to be tightened. The new employee goes about the organization looking for screws to tighten and tightens them. Eventually, however, there are no screws left to be tightened. Looking for new opportunities to apply the skill of using a screwdriver, the employee gets out a hacksaw and starts filing slots into the heads of nails. As silly as this story may seem, it is unfortunately representative of applying inappropriate techniques to the solution of a problem.

Quantitative tools and techniques reduce uncertainty and provide valuable optimization techniques for decisionmakers. However, only limited application has been found in research and development management in large corporations because of data limitations and mistrust of autonomous optimization algorithms (Twiss 1980). As important as quantification is to removing uncertainty and guiding management decisions, the art of quantitative systems analysis still lies in the analysts' and decision makers' ability to judge which uncertainties are being removed advantageously and, conversely, which ones fit the Procrustean metaphor. Correctly applying quantification will usually make the difference in whether system goals are met. Krone (1980) presents a summary of potential pitfalls in the use of quantitative techniques in table 2.

Table 2.--Some pitfalls in the use of quantitative models and techniques. Source: Krone (1980) and author's interpretation.

Adapting the problem and the real world to fit the formula (the Procrustean metaphor).
Model reification (fascination and preoccupation with details of the model, while being overcome by events in the real world--"seeing the trees and not the forests").
Ignoring the axiom of "appropriate methods for unique problems."
Overconfidence and oversell.
Oversophisticated models and techniques requiring non cost and benefit allocation of resources.
Using the wrong model for the problem.
Using the right model incorrectly.
Tautological solutions (those highly sensitive to the statement of the problem and methodology employed).
Making a Butch (Herman Kahn's "completely mistaken technical notion or fact"1).
Interest in only the worth (economic utility) of the outcome and not the values of the system.
De-emphasis or ignorance of qualitative or extra rational components because of relying on mathematics and associated rational models of policy making.
Overuse of technical or mathematical language, thus failing to communicate.

[1] A classic cross-cultural Butch was the translation of President Carter's welcoming statement in Warsaw, Poland, in 1977 from "I have a desire for peace" into "I lust for Poles."

Qualitative Analysis and Expert Judgment

Well defined and documented quantitative analysis is the preferred method of analysis and problem solution. However, this limits the appropriate set of problems to which these techniques will work, and the smart analyst or scientist will avoid those that do not fit the assumptions or algorithms (e.g., the so-called fuzzy systems). Conclusions drawn in the absence of quantitative measurement will have doubtful validity. On the other hand, action taken solely on the basis of quantifiable variables can lead to inappropriate, wasteful, noneffective, or undesirable results (Krone 1980). Fortunately, the choice is not an either or one, but one of sensible use of both quantitative and qualitative tools in an intelligent manner to enlighten decision makers rather than to obfuscate the problem. The central component of the analysis may be quantitative, qualitative, or most likely a mixture of the two. As Krone states:

> "The object of including explicit qualitative methodologies is to provide analysts and decision makers with a rational means for the inclusion of those qualitative and often extra rational--variables in the analysis. The problem for the analysts is not whether those qualitative variables do exist in human systems. They do exist. The problem is how to rationally consider those variables on the assumption that the alternative is for them to remain implicit and unanalyzed, while they continue to move systems toward quality improvement or deterioration. If their influence is toward improvement, we would like to know more about the functioning of those variables so the process can be continued, expanded, and duplicated in other systems. If the influence is toward deterioration, we want a capability for identification, evaluation, and rectification before system failure becomes irreversible. We cannot cure an unknown system pathology. One lesson of the 20th century is that hidden pathologies tend toward system breakdowns rather than self-amelioration."

The idea here is to determine quality as measured against some standard that is measurable and can be explicated. The methodology is conceptually very simple but operationally

often complex. The theoretical process involves two steps: (1) determine the quality using criteria and (2) judge that quality by comparison with standards. One important way to incorporate subjective or tacit knowledge in a system is by cognitive science using expert systems (Cleaves et al. 1987). Farnum and Lembersky (1987) found that by incorporating managerial judgment into a large simulation system that they called "this system of manual optimization," there was a better understanding of the process by management decision makers and a more realistic definition of problem objective functions and constraints.

The primary criterion is the dependent variable, stated in overall terms, for determining quality of a system in evaluation. The total net desired output is determined by it. It is not usually easy to measure, therefore, this requires the establishment of secondary criteria that are subcomponents of a system chosen for evaluation because they are correlated with and more measurable than the primary criterion. The secondary criteria become independent variables to shape the quality of the net output. They are components of input such as people, raw materials, structure, process, or output for evaluation. The primary criteria are organizational effectiveness, goals, or strategies.

Take care in choosing secondary criteria so that what you select is not just convenient to measure and that the resulting numbers fit conveniently into mathematical or economic formulas or into computer programs. There are always alternative standards to measure the quality and whether the primary goals of a system are met. Standards may be derived from both rational and extra rational variables. It is usually better to explicitly include extra rational components in the system whenever possible, because it is analytically useful to consider whether they are positive, neutral, or negative in the performance of the primary system objective. This brings us to the concept of systems leverage, which accounts for the fact that small improvements in one or more components can have significant leverage effects but in opposite directions. This is why the selection and continued review of secondary criteria for evaluation are important to the success of an enterprise. For example, if the lack of effective marketing of products produced is a limiting factor of profitability of an enterprise, a marketing initiative may be needed. Similarly, research on new residential building systems may not be effective because of restrictive building codes, lack of financing by mortgage companies, and consumer preferences for traditional housing.

Feasibility Analysis

There are two main tasks for our conceptual approach to feasibility analysis. First, to design the overall system in which the feasibility analysis subsystem is embedded, and second, to define the particular systems framework for feasibility evaluation. To place our analysis in the proper perspective, we will look at methodological considerations.

There are three fundamental and interrelated categories of research methodologies for systems analysis: (1) behavior research, (2) value research, and (3) normative research. There are also three basic categories of feasibility: (1) economic, (2) technical, and (3) socio-political. These categories of research and feasibility analysis are all interrelated in determining the system design and subsequent problem statement. Economic feasibility is the probability that economic resources are available to meet the goals of the system. Within economic feasibility analysis, it may be important to conduct a marketing feasibility study. Also included are the economical development of resources and the economic assessment of conversion processes that can efficiently produce products that are acceptable to the consumer. Technological feasibility is the probability that the scientific and technical development goals of the system are met. Socio-political feasibility is the probability that the policy or technological alternative will be acceptable to the user, decision maker, or society.

Feasibility of the conversion process, in the context of the overall resource system, is the principal concern of this paper. The economic feasibility of resource conversion is the particular subsystem that I will examine. Economic feasibility is related to technical and socio-political feasibility as well. The three feasibilities are mutually supportive even though they may use data from different sources. Economic feasibility has a great deal to do with the status of technology; technology is partially dependent upon budgets for research. Political feasibility may be determined by professional technological or economic feasibility studies. Care must be taken to consider this interdependence when conducting feasibility analysis. Economic feasibility will also interface with the available resource system and the market and consumption systems.

There are several steps in the economic feasibility analysis. The first is assessment of a need, the second is project definition, and the third is project evaluation. The first step is to identify the need to be met by the project and then to define the system goals for the project. For example, economic development may be a system goal. Utilization of a surplus forest resource, such as eastern hardwoods, may be another type of goal. The establishment of need, such as the ability to compete economically or establishing community stability through resource development, can then be translated into specific goals of greater utilization of northern hardwoods in the United States. This goal then needs to be made operational by the establishment of criteria for evaluation and measurement.

The appraisal criterion is then an important factor in determining the type of project selected for feasibility evaluation. The following criteria may be required for project evaluation: (1) organization objectives, policies, and values; (2) market needs, consumer acceptance, and marketing; (3) research and development; (4) financial; (5) production or process; (6) environmental or ecological; and (7) social and political acceptance. Note that net output can be misleading as a criterion because it measures the wrong thing. For example, if return on investment over time is allowed to become the primary criterion of a

business organization as opposed to a broader criterion of organization health and productivity, a secondary-to-primary criterion transformation has taken place that could be costly, risky, or even fatal (Krone 1980). A similar problem can exist when return on investment is used as the primary criterion to justify environmentally unwise projects in some developing countries. As Gold (1988) states:

> "The most common approach to evaluating prospective technological innovations involves two steps: evaluating their expected cost savings and revenue increase relative to current capabilities; then comparing resulting gains (discounted to determine their present net value) with their investment requirements, i.e., the usual capital budgeting approach. But this essentially is the wrong criteria.
>
> "After all, the basic objective in adopting major technological innovations which embody significant investment for many years must be to safeguard or improve a firm's competitiveness over an extended future."

"For a public enterprise the main goal is to provide benefits for the nation and to improve the national efficiency," to quote Gifford Pinchot. To do this all the components of the system under study must be scrutinized. This includes all the inputs to the conversion process over time.

According to Clifton and Fyffe (1977), a complete study of project feasibility includes: (1) market analysis, (2) technical evaluation, (3) a financial analysis, and, if needed, (4) a social profitability analysis. The market analysis involves the search for an analysis of data that can be used to identify, isolate, describe, and quantify the market. This study can be used to identify user needs. A market study generally should contain: (1) a brief description of the market, (2) an analysis of past and present demand, (3) an analysis of past and present supply, (4) estimates of future demand for the product, and (5) estimates of market share both domestic and foreign.

Technical analysis serves to establish whether or not a project is technically feasible or what research needs to be accomplished to make it so. It also provides a basis for cost estimating. The technical analysis should contain a review of techniques or processes to be applied and include: (1) description of the product, (2) description of selected or desired manufacturing process, (3) determination of plant size and schedule, (4) a study of available raw materials, (5) an estimate of labor requirement, (6) a plant location study, environmental costs, and (7) estimates of production cost for product.

Financial analysis concentrates on determining whether a project is profitable from a commercial standpoint or whether a project achieves a minimum threshold rate of return and on the amount of capital required to implement it. Information from the market and technical analysis is used to determine financial measures. A sensitivity analysis or risk analysis may also be conducted. For new projects an estimate of total project costs, capital requirements, and cash flow is desirable. An analysis of rate of return on investment and price sensitivity is also needed. A sensitivity analysis and risk analysis may be made to identify items that have a large impact on profitability.

Finally, a social profitability analysis may be performed if there is public involvement or there are established national priorities. The social profitability analysis is an evaluation of the contribution of the projects to the economy. This includes the evaluation of the project toward meeting goals such as increasing employment or net foreign exchange benefits. This may include goals of increasing markets for wood products or improving national competitiveness. Generally. some cost-benefit analysis is used in conjunction with these social objectives.

The Forest Resource System

This paper concentrates on the relationship of forest product utilization technology to the analysis of economic feasibility of forest product development that in turn is related to forest resource management. The concept of the forest as a system as explicated by Duerr et al. (1979) is useful here. They state:

> "A major aim is to focus the work upon integrated forestry: the creation and use of all forest values from scenery to wood. We have tried to see forestry as a system of interacting variables and also as a part of a larger social system that in the final analysis is the sum of human experience. Another aim is to view forestry not as a set of rules, but as a set of resource alternatives. Still another is to demonstrate how modern quantitative methods of generating information can fortify judgement in choosing among resource alternatives."

Thus, the forest can be viewed as a social-biological-engineering system. We can also define three major components of the overall forest resource system: the timber-output system, the technologically defined conversion system, and the marketplace where the consumption interface occurs. The forest resource system is dynamic, that is, it changes continuously through time in many dimensions--biological, technological, economic, socio-political--that are changed by humans through management activities. Most systems analysis studies in forest resources concentrate on the timber-output system. This system usually has four subsectors: timber inventory, timber growth, timber management, and timber removal. This is the major part of the timber resource system from the foresters viewpoint. However, from an overall systems analysis viewpoint the other components, the forest product conversion system and the market and consumption interface are also important as are the interactions between the subsystems through time.

This paper concentrates on the forest product conversion system in the context of the overall forest resource system. The conversion process for forest resources is part of the overall forest resource system (Bethel and Schreuder 1976). The material supply operation is a function of the match between the

resource and the conversion and marketing system available to the resource. If the material being recovered is very valuable (e.g., gold, platinum, or silver), a relatively inefficient materials recovery system involving large expenditures of capital, energy, and labor per unit of material output may be economically feasible (Bethel 1980). Though it is not always recognized, a similar situation exists with forests. The total biomass of the forest is available for utilization at a cost. This includes trees, stems, branches, and even stumps and roots. Trees too small, crooked, or of the wrong species are also available. Mill residues, such as bark, slabs, edgings, trimmings, core, clippings, and round up, are also available at the conversion stage. According to Bethel, a utilization efficiency can be defined for a wood material supply system as the mass of material produced by the system as a fraction of the total stem biomass of the forest. Analogous to the metal materials supply system, a forest-based system can have low efficiency for high-valued materials like black walnut, mahogany, or rosewood. But, the efficiency must be much higher for low-market value material if it is to be economically feasible.

The forest-based materials supply is biologically renewable and therefore can change through time. Manipulation of the forest on the one hand and the manufacturing facilities on the other hand permit progressive improvements in utilization efficiency. A large simulation model was developed by Farnum and Lembersky (1987) for Weyerhaeuser Corp. that illustrates the interrelation between timber and conversion technology. The model was used to derive normative timber management strategies for future plantation based upon alternative growth and mill conversion assumptions. The model had four modules: biological growth and yield, harvesting and handling cost and productivities, mill conversion recoveries and values, and financial returns. A combination of an approach using judgment based on managerial experience was used rather than strict mathematics to develop a system of manual optimization. Using this system, they showed how advanced sawmill technology using small logs would provide a superior alternative to the conventional utilization and management systems.

These opportunities for change in the system permit reaction to changes in market preferences and conversion technology. Changes in the forest-based material supply system occur slowly over long time periods and generally require considerable expense. Bethel (1980) cites an example of such a system applied to tropical hardwoods. It includes a reference material system (RMS) as the integrating and synthesizing component (Bhaget and Hoffman 1980).

This illustrates the systems analysis approach to economic feasibility analysis for forest products utilization. With the use of process conversion models and proper data, the forest materials supply system can be evaluated in terms of utilization efficiencies. The results can be portrayed in the form of RMS. In a similar way, the flow of capital, energy, and labor can be evaluated through the material production system. Environmental considerations can be considered as constraints on the system.

Technology changes occur over longer periods of time. These technological changes influence wood utilization efficiencies. The rate of technological change can be effected by forest products research efforts. Therefore, technological change and research components are also included in the concept of systems analysis through time or a dynamic systems analysis.

The Forest Utilization System

The conversion or manufacturing process can be viewed as a system-determined science (Casti 1987). The conversion process is a multifaceted system that can be viewed from a number of perspectives of the overall process. The conversion process system can be expressed in a hierarchical fashion with raw materials being the lowest level and values the highest. What determines a systems problem in manufacturing is the relative emphasis upon issues of process and function, grounded in constraints from the natural resources, requiring a knowledge of several disciplines.

The concept of process implies that all of the inputs to the conversion process should be considered for change. A new machine or a method of organization that reduces the cost of production and thereby increases the efficiency of producing an existing product is just as important as development of a new product. The weakness in process technology in the United States has been pointed out by Thurow (1987).

The conversion process in forest products is typically product orientated. The customers or end users are not generally considered in this mold. Marketing considerations for customers holds that products are not an end in themselves but merely the means to satisfy the customers needs or desires. Feasibility analysis begins with the determination of research studies to satisfy identifiable human needs. This considers the process as being the conversion of scientific knowledge directly into the satisfaction of customer need in the market and consumption interface. The product then becomes merely the carrier of the technology and the form is only defined after the technology and the need have been clearly matched. Similarly, available forest resources should guide technological feasibility for particular regions.

Conclusion

The production of timber products generally leads to preoccupation with things rather than the concept of process. Forest industry is perceived as a process that converts raw materials from the forest into products, which in turn are converted into money by selling to customers who are willing to pay more for these goods than it costs to produces them. The margin between the price paid and the cost to produce yields is the profit that can be reinvested to sustain growth of the industry and provide wealth to shareholders directly and to society indirectly.

Most analysis and planning systems are resource driven. The viewpoint of this paper is that they should be driven by market and consumption systems and the technology and conversion systems, which may be a constraining factor and can be changed by research or technical development. The resource system is also modified by cultural activities, environmental change, and other biological factors. Capital investment and prospective future investment are also important factors. Existing establishments tend to want to prolong the status quo and maintain vested interests. What is needed is an outside look that utilizes available resources and ideas (Drucker 1988).

Business-driven resource decisions are viewed as generally preferred to those based only on timber-output system decisions. Better yet are ones in which the biological and resources system interfaces with a market and consumption system and a conversion and technology system. A good example of business-driven strategy is the development of the composite panel products, like waferboard utilizing aspen that was a surplus resource and was inexpensive to grow in the Midwest. High-cost plantations of red pine might have been the conventional resource manager's alternative for forest development in the 1950's. Systems analysis provides a way to look at forest resource management and development and broaden the perspective of the management decision making when looking at factors other than the resource base.

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Relating Network Analysis Results To Data Uncertainty In Forest Development Applications

Thomas L. Moore, John Sessions, and Robert Layton[1]

Abstract.--Network analysis in forest development applications often assumes perfect information. Monte Carlo simulation is used to test the sensitivity of network analysis results to uncertainty in the data for five forest development network problems. Two of the five areas are found to be very sensitive, two are moderately sensitive, and one network is insensitive to uncertainty in the input data.

To test the sensitivity of network solutions to uncertainty of the data, five typical transportation planning problems were identified from various regions of the USDA Forest Service. Input from the field units consisted of the estimated timber volumes to enter the source nodes, estimated transport costs, and estimated road construction costs.

It is assumed that the field data for the log volumes entering each node and the road construction costs are means of normally distributed random variables. The variance given for the random variables was based upon our experience of the uncertainty that could be expected in the field. One hundred variates from each distribution were chosen and the network solution which minimized road construction and transport costs was determined for each set of randomly selected timber volumes and road construction costs. The number of solutions with common paths were then identified. The frequency of occurrence of the solution identified using the original estimates indicates the sensitivity of the network to uncertainty of the data.

Although the analysis presented here could be used for any network analysis application involving fixed costs per link (arc), variable costs per unit flow per link, and units per source node, this analysis focuses on forest development problems.

Background

Network analysis is frequently used in forest development planning to determine the most economical network of roads to construct and the routes over which to transport logs from the forest to the sawmill or other destination. The sources where logs enter the transportation system are tracts of timber in the forest, and the sinks or destinations are the manufacturing facilities. The data in the analysis specifies the volume of logs entering the source node, the cost of road construction alternatives to access the sources, and the cost to transport the logs from the sources to the destinations. The road construction costs are referred to as "fixed costs" and the transport costs are calle "variable" costs. The road and route optimization problem i known as the "fixed charge" problem in operations research. I is usually solved by either mixed integer mathematical pro gramming or by the use of a heuristic method. Several networl analysis programs are commonly used by the USDA Fores Service. These programs include: NETWORK, MINCOST TIMBER TRANSPORT, and the TRANSHIP model and ar described by Moore (1987).

Study Areas

Five study areas, varying in size and complexity, wer selected from national forests throughout the United States. Th study areas are referred to as: Off Planning Area (fig. 1), Giffor Pinchot National Forest, Washington; Peavine Planning Are (fig. 2), Eldorado National Forest, California; Silver Plannin Area (fig. 3), Nezperce National Forest, Idaho; Kosciusk Planning Area (fig. 4), Tongass National Forest, Alaska; an Beaverdam Planning Area (fig. 5), Cherokee National Fores Tennessee. Important characteristics of each network ar shown in table 1.

[1] *Civil Engineer, Umpqua National Forest, USDA Forest Service, Associate Professor, Forest Engineering Department, and Professor, Civil Engineering Department, Oregon State University, Corvallis, OR.*

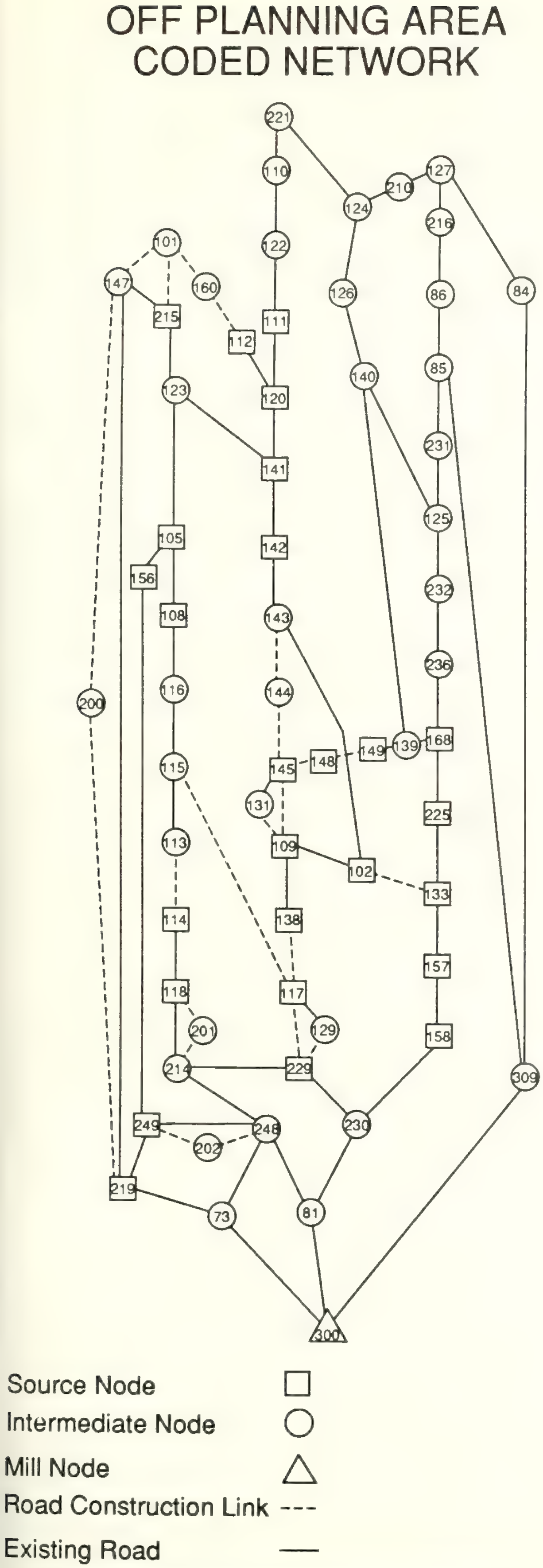


Figure 1--Network schematic for Off Planning Area.

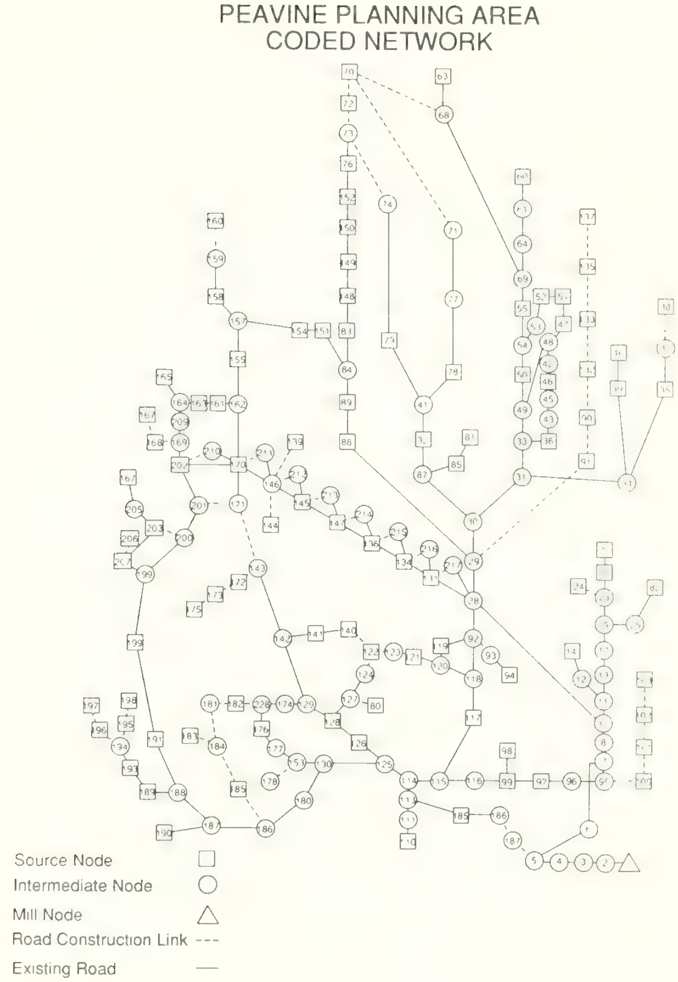


Figure 2--Network schematic for Peavine Planning Area.

Description of Sensitivity Analysis

Data collection for a network analysis study can be difficult and expensive. The quality of information needed for the analysis to be meaningful is generally unknown. The analysis could be invalid if the data estimates were significantly different from the actual values occurring in the field at the time of implementation. Errors, to some degree, are expected for every item of data used in the analysis. Therefore, the question is "how much error can reasonably be expected in the data and how do these errors affect the results?"

Monte Carlo simulation (Degarmo et al. 1984) is used in this analysis as a technique to aid in estimating the quality of the results. The original data are assumed to be the means from normally distributed random variables. The standard deviations are estimated from previous Forest Service experience. The ratio of the standard deviation of the timber volumes to the mean (coefficient of variation) is assumed to be 0.3. Similarly, the fixed costs are assumed to have a coefficient of variation of 0.2. The variance of transport costs is not considered in the analysis because the Forest Service collection schedule for transport costs is fixed.

The network from each planning area is then analyzed 100 times, each time substituting variates from the assumed distributions for the timber volumes entering the network and the construction costs for proposed links. The NETWORK program was used because a previous study evaluating the performance of several network analysis models using these five study areas showed the NETWORK program provided the best results (Moore 1987).

Each of the 100 scenarios (simulations) and corresponding solutions represent one possibility for the true optimal solution when the project is implemented. A different set of solution paths might result from each simulation or all of the 100 solutions might be the same. The frequency with which the solution paths change represents the sensitivity of the individual network. The "Stability Index"[2] indicates the sensitivity of the network to variability in the input data. The Stability Index is defined as the percent of total simulations run having the same solution paths as those chosen by an analysis using the original data (means). The Stability Index value is calculated as:

[2]*More (1987) refers to this value as the Sensitivity Value in earlier paper.*

$$\text{Stability Index} = \frac{\text{No. of Simulations w/Original Sol. Paths}}{\text{No. of Simulations}} * 100$$

A Stability Index value of 1% indicates that only one of 100 simulations arrived at the same solution identified using the original data. A Stability Index of 100% indicates that all simulations have the same solution as the original solution. The "Maxsim" value is the percent of simulations having the largest number of identical solutions. This value is calculated as follows:

$$\text{Maxsim} = \frac{\text{Maximum No. of Identical Simulations}}{\text{No. of Simulations}} * 100$$

The Maxsim value is significant because it may identify a solution set that has a higher probability of being selected than other solution sets. The Maxsim value can never be lower then the Stability Index value, and in many instances, they will be identical.

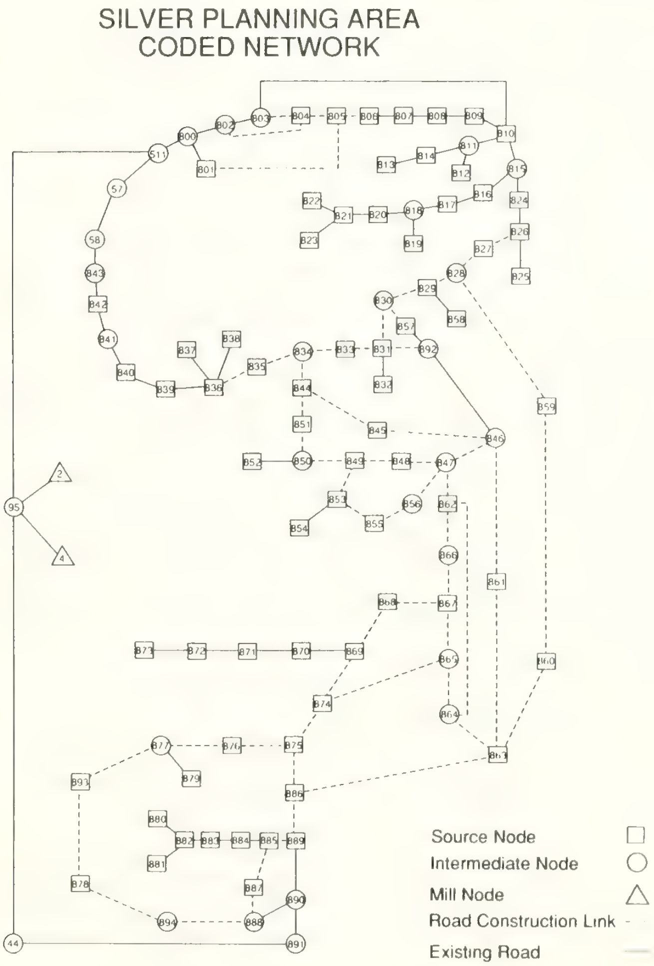


Figure 3--Network schematic for Silver Planning Area.

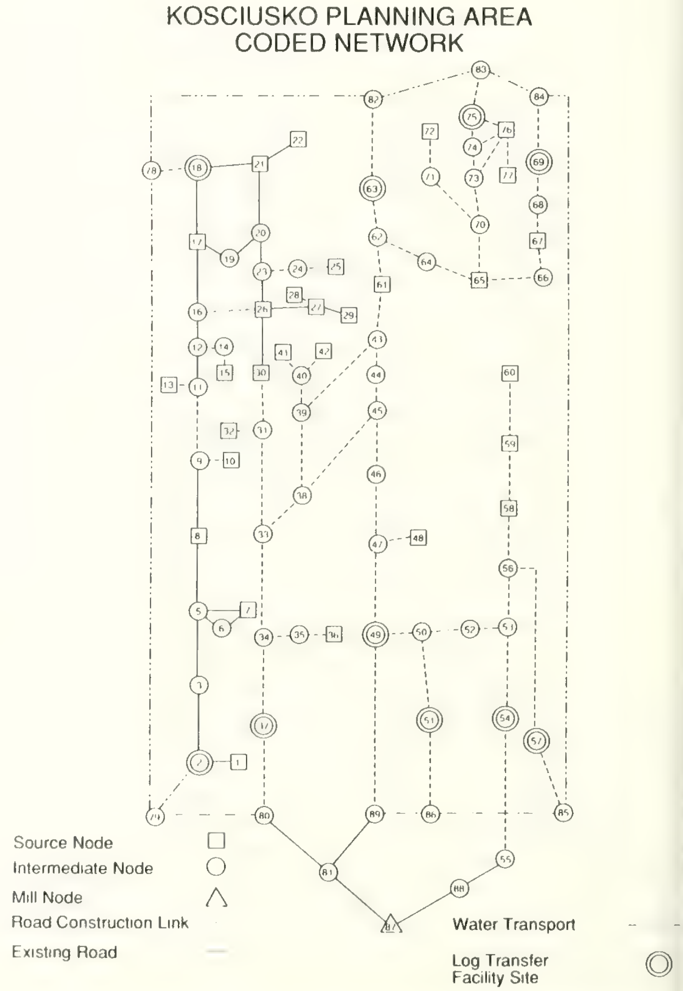


Figure 4--Network schematic for Kosciusko Planning Area.

Example Problem

The example shown in figure 6 is analyzed to demonstrate the analysis procedure. Assume there are five paths from one source node (timber sale) to a destination (mill). The solution with the lowest cost to this problem using the original data is $1,000 corresponding to path S-$1,000-M (fig. 6). One might ask, "Is this path truly the lowest cost or is there another path that has less cost when uncertainty in the data is considered?"

Five simulations are performed to illustrate the process. The original data are used as means to generate values of normally distributed variables. Five data sets are created representing five possibilities for the actual data that could be observed in the field at the time of implementation. The first simulation is described in detail. The random numbers used to arrive at the other four data sets (revised data) are not included.

Figure 6 shows the random normal numbers and data set for the first simulation. The lowest total network cost of the first simulation using the revised data is $1,067 which corresponds to path S-$1,200-M. The total cost for this network after substituting in the original data is $1,200. Table 2 summarizes the results of the five simulations.

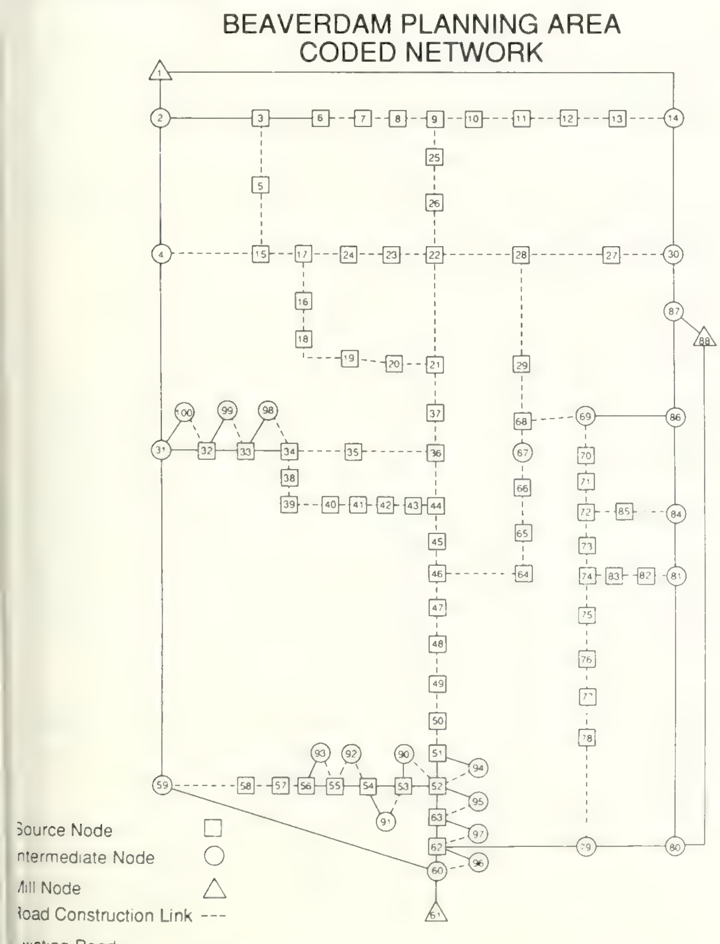


Figure 5--Network schematic for Beaverdam Planning Area.

Table 1.--Classification of networks from project areas.

Net. attributes	Off	Peavine	Silver	Kosciusko	Beaverdam
No. of sales	26	99	71	29	70
Total nodes	64	191	105	88	100
No. of arcs	169	338	170	153	213
No. of projects	22	55	58	69	84
No. of mills	3	1	2	1	3
No. of links	84	215	116	102	125
Sale volumes (mbf)					
Avg. (c)	3,281	528	1,330	9,900	207
S.D. (s)	3,436	756	700	10,970	285
Fixed costs					
Avg. (c)	218,300	18,400	61,900	305,850	5,090
S.D. (s)	257,800	43,300	35,800	462,739	3,740
Variable costs					
Avg. (c)	5.06	1.75	2.05	2.73	1.41
S.D. (s)	10.80	1.60	2.24	6.59	0.74
% of sale node in NETWORK	41%	52%	68%	33%	70%
% of links having fixed costs	26%	26%	50%	68%	67%
No. of 3-node loops	4	8	0	1	11

Table 2 shows that only one simulation chose the same solution path identified using the original data, i.e., path S-$1,000-M. Path S-$1,200-M was selected three times and path S-$1,100-M was selected once. The Stability Index value is:

$$\text{Stability Index} = \frac{1}{5} * 100 = 20\%$$

The Maxsim value for this example is:

$$\text{Maxsim} = \frac{3}{5} * 100 = 60\%$$

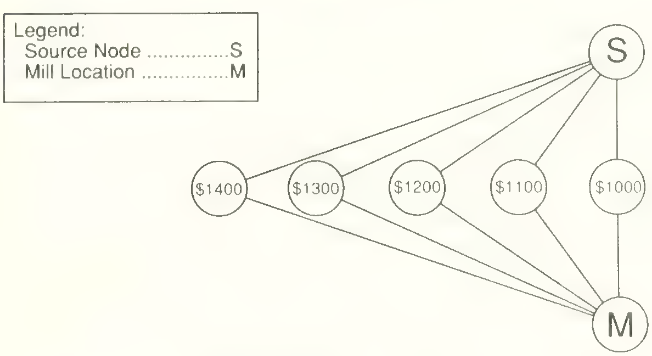
Since the Maxsim value is higher than the Stability Index value, the solution associated with the Maxsim value has a higher probability of being the optimal solution than the original solution set identified by the Stability Index. This does not mean however that this should be the solution selected for implementation. The paths associated with the Maxsim value, which have a higher probability of being the optimal when considering number of simulations run, will have a solution cost which is only slightly lower than the original solution. However, the paths associated with the Stability Index, although having a lower probability of being the optimal solution when evaluating strictly the number of occurrences, will be a much better solution when it is chosen.

The following example illustrates this point. Assume five simulations are run on a small network and all five results can be categorized as using the arcs in either Network A or Network B. The solution costs are:

Simulation #	Network A	Network B
1	$420	$380
2	$400	$390
3	$410	$400
4	$400	$390
5	$100	$500
Mean of solutions	$346	$412

The mean of the five solutions for each network is equal to the solution using the original data, therefore, the optimal solution identified by using the means of the data would be Network A. From the above example, Network A is superior to Network B for only one of the five simulations, i.e., Simulation Number 5. For the other four simulations, Network B has the lowest cost. The Stability Index value would be 20% and the Maxsim value would be 80%.

It would appear that Network B would be the better solution to implement; however, when Network A was better it was much better causing the mean of the solutions to be lower for Network A. For large organizations and agencies that can absorb moderate losses, adoption of Network A would provide the lowest expected cost. A small organization interested in minimizing the level of risk associated with an investment, might choose Network B even though it is not the lowest cost solution identified using the original data.



Simulation Data

Link	Random Normal Number		Std. Dev. **		Original Link Cost		Revised Cost
S-$1000-M	[+.805	x	$200]	+	$1000	=	$1160
S-$1100-M	[+.603	x	$220]	+	$1100	=	$1232
S-$1200-M	[-.551	x	$240]	+	$1200	=	$1067
S-$1300-M	[+.024	x	$260]	+	$1300	=	$1306
S-$1400-M	[+.125	x	$280]	+	$1400	=	$1435

NOTE: Lowest total cost = $1067 corresponding to path S-$1200-M

** Standard Deviation = 0.2 x original link cost

Figure 6.--Network example showing costs associated with five paths from the sale node to the mill node and details of one simulation.

Table 2.--Summary of simulations.

Simulation #	Total cost with revised data (random variables)	Selected path	Total cost with original data (means)
1	$1,067	S-$1,200-M	$1,200
2	880	S-$1,000-M	$1,000
3	1,242	S-$1,200-M	$1,200
4	1,030	S-$1,100-M	$1,100
5	1,246	S-$1,200-M	$1,200

Application of Sensitivity Analysis to Study Areas

The approach described above was applied to the five field problems described earlier. A total of 100 simulations were made for each study area using the NETWORK model. The Stability Index and Maxsim values for each of the five areas are shown in table 3.

The Off Planning Area generated the highest Stability Index value of 76%. The Maxsim value for this area is also 76%. This network is relatively insensitive to the assumed variability in the input data.

Beaverdam and Silver Planning Areas are the most sensitive networks both having Stability Index values of one and a Maxsim value of two. Since both values are very small, further analysis is needed to determine which links in the network are used more than alternative links to attempt to narrow the focus of the subsequent analysis.

Peavine and Kosciusko both have Stability Index values close of 50%. These two are moderately sensitive networks.

Additional Implications of Sensitivity Analysis

Network sensitivity also provides an indication of the accuracy of the data needed. For example, the Off Planning Area, classed as an "insensitive" network, could tolerate a significant degree of variability in the input data and the same set of solution paths as the original solution set was selected 76 out of 100 simulations. Therefore, the data for this area need not be exact to identify the optimal solution. The collection of data used for this network need not be as intensive as with areas that are more sensitive. Peavine and Kosciusko, with moderate

Table 3.--Summary of stability index and maxsim values.

Planning area	Stability index value	Maxsim value
Off	76%	76%
Peavine	47%	47%
Silver	1%	2%
Kosciusko	48%	48%
Beaverdam	1%	2%

sensitivity values, would require more accurate data than Off Planning Area. Beaverdam and Silver, which are the most sensitive networks, require very accurate data for the analysis to be valid. It may not be possible to achieve this accuracy.

In addition to having uncertainty in the data, forest planning also involves resources for which some costs are intangible. Sensitivity analysis provides the probability of occurrence of alternative solution paths. This information can help the decision maker to weigh tangible and intangible costs. He might choose a solution with a higher expected cost if the probability of an outcome with a desirable intangible value is relatively higher.

Conclusions

Simulation can be used as a technique to evaluate the behavior of networks. Stability Index values that are high indicate relative insensitivity to variability in the original estimates. Values that are low identify sensitive networks and may require individual link analysis to determine the selected solution. Performing a sensitivity analysis on five field problems indicates that only the Off Planning Area is "insensitive" to the assumed variability in the input data.

The sensitivity of the network gives an indication of the accuracy of the data needed. Very sensitive areas require more accurate data than insensitive areas to provide meaningful results. Networks could be pretested to determine their sensitivity to establish data collection requirements.

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From Growth Models to Short-Term Timber Sale Scheduling: Design For a Flexible Link Serving Multiple Clients

P.J. Daugherty, J. Keith Gilless, Frieder Schurr, and Lawrence S. Davis[1]

Abstract.--The information forest managers need for short-term timber sale scheduling is a function of the owner's goals and constraints. A set of five computer programs, called the Stand Evaluator, provides a flexible link between timber sale scheduling programs and CACTOS and CRYPTOS (two California growth and yield simulators). The Stand Evaluator's programs post-process growth and yield data, averaging tree lists, simulating the bucking of trees into logs, valuing these logs, and producing a summary economic report. The user defines stand types and management units, and supplies bucking rules and economic data. Each program preserves intermediate results in a compact standardized data file. The flexibility of this link between growth and scheduling models results from preservation of intermediate data, a program structure that facilitates user modification, and reliance upon user-designed programs to meet specialized needs.

Stand or stand type growth and yield information requirements for short-term timber sale scheduling depend upon the owner's goals and constraints. Owners selling stumpage may be primarily concerned with total volume by species, and how this changes over time. Forest owners selling logs may be more interested in the distribution of volume by log size, and logging and hauling costs. Industrial owners with processing facilities may face constraints on species and log size distribution. Forest owners with multiple-use goals may have a wide variety of informational needs. For example, the canopy closure at different heights in a stand can serve as an index to bird habitat capability, and the distribution of stands by average diameter, basal area, and height may be useful for addressing visual resource requirements or wildlife concerns. To serve a diverse clientele, the design of a system for processing growth and yield data for forest management planning requires special attention to maintaining flexibility of access to the data and program functions.

[1]*Graduate student, Assistant Professor, Junior Specialist, and Professor, respectively, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720*

This paper discusses the design of a package of five com puter programs, called the Stand Evaluator, that provide flexible link between timber sale scheduling programs and th CACTOS and CRYPTOS programs. CACTOS, the CAlifornia Conifer Timber Output Simulator (Wensel et al., 1986), is growth and yield model for young-growth mixed conifer stand in northern California. CRYPTOS, the Cooperative Redwoo Yield Projects Timber Output Simulator (Wensel et al., 1987) is a similar model for the coastal redwood-Douglas fir region o California. Both are individual-tree, distance-independen models developed by the biometrics group at the University o California, Berkeley. The Stand Evaluator was develope under the auspices of the Economics/Management Project o the California Forest Research Association, an association o academic, industry, and governmental institutions.

Problem Definition

The cooperators funding this project included the Univer sity of California, the California Department of Forestry an

Fire Protection, five forest products companies, a private consulting company, and a public utility company. This group's diversity, along with the Land Grant mission of the University, provides a good example of the multiple client situation in which a broad range of goals and constraints are represented.

The diversity of goals and constraints was accompanied by diversity in informational processing capabilities and forest management decision models. Informational processing capability ranged from clients just beginning to use microcomputers to others operating integrated mainframe geographic information database management systems. Management decision models ranged from heuristic rule-based systems, in which stands are ranked by present net value, to sophisticated linear programming models with customized matrix generators. Figure 1 illustrates where the Stand Evaluator fits into the processing of growth and yield data in the context of clients with dissimilar information processing capabilities and decision models.

While the multiplicity of intended applications mandated a flexible design, our clients had common needs which anchored certain components of the Stand Evaluator. The basic unit of analysis for all clients was the stand or stand type. Both CACTOS and CRYPTOS are plot-based models. Hence the Evaluator had to be capable of aggregating plot-based data to the stand or stand type level. All clients had an interest in both short- and long-term timber sale scheduling. All wanted to be able to specify prices and cost estimates on volume by species and log size. The prevalence of multiple inventory plots per stand type required capacity for massive data throughput. In addition, all clients anticipated future increases in their information needs. Finally, all wanted built-in summary report writing capability for management units (or sets of stand types).

Design Criteria

Design criteria evolved from several meetings with our clients. These criteria fall into two overlapping categories dealing with program flexibility and common functional needs.

Flexibility Criteria

1. The system must allow use by clients with different goals and constraint sets.
2. The system must operate on micro, mini, or mainframe computers.
3. File handling conventions must allow for integration into geographic information data base management systems, while remaining usable by clients with less sophisticated data processing capabilities.
4. Output must allow for summarization at different levels of detail, and be suitable for forest management research.
5. The system needs to be easily modifiable to meet clients' specialized needs, and expandable to meet new information requirements.

Common Needs Criteria

1. The system must be capable of aggregating plot level growth data to the stand level.
2. The system must allow processing of either single plot or multi-plot data.

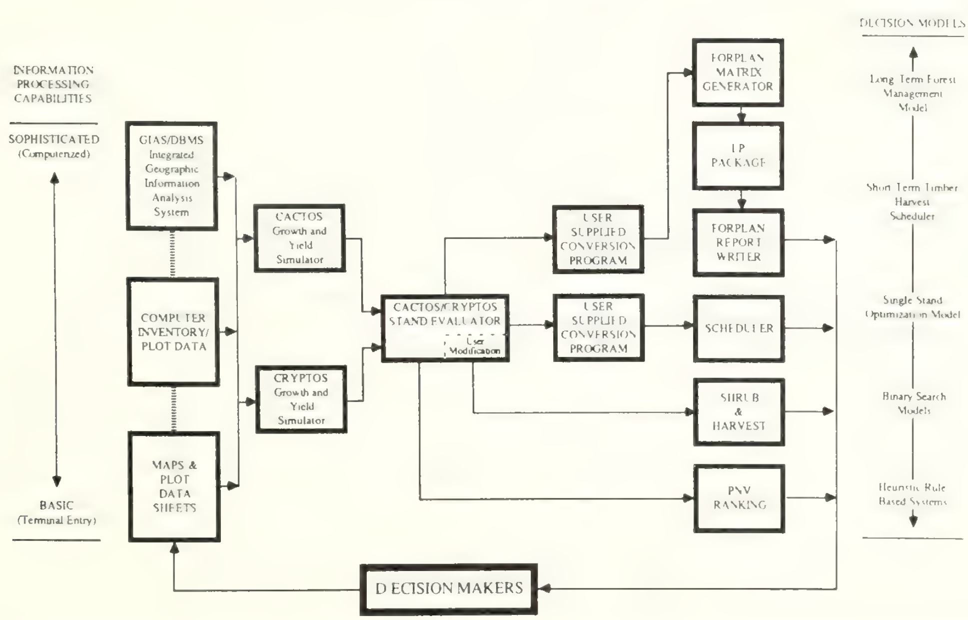

Figure 1.--Role of the Stand Evaluator in providing a flexible link between growth and yield models and short-term timber sale scheduling for diverse clients.

3. The stand level output data must be suitable for both short-term timber sale scheduling (i.e. annual growth and yield) and long term planning (i.e. periodic growth and yield).
4. The system must produce volume estimates, by species and log size, under a variety of bucking rules.
5. Valuation of volume must allow for consideration of price and cost schemes of different complexity.
6. The system must allow for the data throughput needed for detailed analysis of stands in decision making.
7. The system must have built-in summary report writing capability for user-defined management units.

System Design and Function

Overview

A modular system design for the Stand Evaluator (fig. 2) was developed to meet the above criteria. Each square box represents a single purpose program designed to perform a specific function. The Stand Evaluator programs are linked by compact standardized input/output data files which allow for multiple entry and exit points in the implementation of the system, and preservation of detailed intermediate results. The programs are minimally-interactive, batch-oriented processors suitable for linking by job control language. Each program has one or two control file(s) that allow for user specification of stand types, bucking rules, price and cost data, economic trend data, and management units. The FORTRAN code for each program was structured to facilitate user modification and addition of new functions and subprograms. The implementation of the system relies on user design programs to meet specialized needs.

System Components

CACTOS and CRYPTOS are capable of producing tree list files that represent the simulated development of a stand over time, allowing for intermediate harvests and ingrowth. These files contain a sequence of tree records and summary data describing the initial stand, and each growth cycle, harvest entry, and ingrowth addition. Five-year periodic growth equations are based upon plot level data, and predict the growth of individual tree records that describe the trees found on plots representing the stand type of interest.

The first Evaluator program, CTLAVG (the tree-list-averager) aggregates plot-based growth and yield data to the stand or stand type level. It produces an average tree list by calculating a weighted average of the plot-based tree lists produced by CACTOS/CRYPTOS. The program averages tree records by two inch diameter/twenty foot height class combinations, weighting by the number of trees/acre each record represents. This method preserves the variability represented by tree records, while reducing the total number of records processed by subsequent programs. The user defines stands or stand types by specifying the plot-based input files to be averaged. Optionally, differential weights can be assigned to input files. CTLAVG calculates a running average, effectively removing any program limitations on the number of plots to be averaged. This technique, coupled with the user assigned weights, allows the combination of new plot data and existing average tree list files.

YDSPLT (the yield-splitter) splits the periodic tree lists produced by CTLAVG into annual tree lists for use in short-term timber harvest scheduling. The user can request annual tree lists five or ten years in length. Standardization of input and output file formats allows users to bypass the CTLAVG program and route CACTOS/CRYPTOS output files directly to YDSPLT.

LGBUCK (the tree-to-log-bucker) converts tree list files into log list files that describe the growth and yield of merchantable timber over time. LGBUCK accepts CACTOS/CRYP-

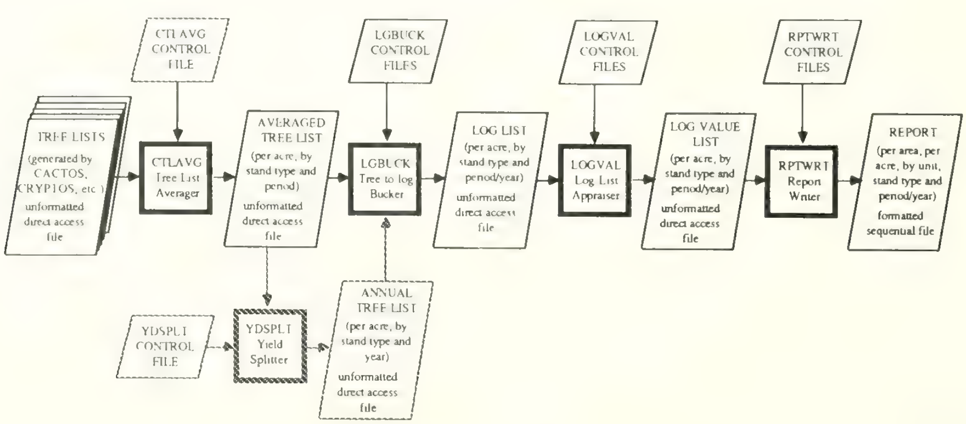

Figure 2.--Stand Evaluator program design.

TOS, CTLAVG, and YDSPLT output files. LGBUCK bucks ree records into log records on the basis of an user supplied control file. This file specifies general merchantability limits i.e., min. DBH, min. top DIB, min. and max. log length, and scaling increment), preferred log lengths, and DIB limits for each length. These rules can be specified by species or species groups. Bucking rules are applied using taper equations to determine DIB at appropriate points on the tree, and the 'bucked" logs are scaled according to Region 5 Scaling Bureau Standards. The program calculates both gross Scribner decimal C board foot and cubic foot volumes. Users have the option of specifying gross to net conversion factors to account for volume oss due to breakage, defect, and cull. LGBUCK writes out volume information by species, log length, and one inch top DIB classes.

LOGVAL (the log list appraiser) produces a log-value list file by associating user supplied prices and costs with individual og records. Prices and up to three types of costs (dollars per unit of volume) can be specified. The values of standing volume, ntermediate harvests, and ingrowth are calculated in terms of he logs that would be produced if the corresponding trees were bucked as specified in the log list. The economic data input file s structured for compact specification of prices and costs. A size dependent price scheme for a species-grade group is specified by listing only the log lengths and DIBs where the unit prices change. Up to five log length breaks, and up to five DIB breaks per log length break, can be listed for each species-grade group. Costs schemes are specified in an analogous manner. Two cost types can be specified by log size, while the third can be specified by species and log size. The former are nominally identified as falling/bucking and skidding costs, and the latter as hauling cost. In practice, the three cost types can be used to account for any unit cost the user wishes to associate with a log. Prices and costs may be specified on either a per board foot or per cubic foot basis.

RPTWRT (the report writer) produces summary economic reports for user defined management units. The units are defined by specifying log-value list files and associated acreage hat occurs in a unit. Trends in prices and costs over time can be specified in much the same format as the basic prices and costs. Trend schemes can be more or less complex than the price and costs scheme, to which they are applied. In addition, up to ten per area or per acre costs can be specified for the management unit or its component stand types. Costs can be further specified as applying to final harvest, intermediate harvest, or both. Users can also control reporting detail, which ranges from a management unit summary to detailed cash flow reports for individual stand types. Pseudo-management units of a single acre can be used to report economic data on a per acre basis.

Flexibility

The Stand Evaluator is composed of stand-alone programs dedicated to specific functions, linked by standardized data files. This design allows individual clients to use only the programs suited to their particular applications. Separation of functions at the program level allows for numerous natural entry/exit points in the system. Standardized data files allow for different paths through the first part of the system. A source language which conforms to an ANSI standard ensures the system's portability to micro, mini, and mainframe computers. The Stand Evaluator was written in STANDARD FORTRAN (ANSI X3.9 - 1977), commonly referred to as FORTRAN 77, for three reasons: (1) it is a widely accepted standard, (2) it is excellent at formula translation, and (3) it was the only language in which programming knowledge was readily available. The program source code follows structured programming conventions in order to facilitate user modifications.

The programs are designed as minimally-interactive, batch-oriented processors. Run-time input is limited to the names of the control file(s). This input is easily incorporated into job control language or batch files, allowing the programs to be run as a seamless batch system. The programs have no internal limit on the number of input files to be processed, so the quantity of data processed in a single run is only limited by disk storage capacity. This feature gives the system considerable throughput capability, subject to users' ability to design batch runs that fit within their hardware's limitations.

To ensure compatibility with geographic information, data base management systems, to combat file proliferation, and to facilitate batch processing, file conventions were developed for opening and naming files. When an error occurs opening an input file, an error message is written to a batch report file, corrective action is taken, and processing of next file or next set of files continues. Output file names are assumed to be "correct", and existing files with the same names are overwritten without warning. The Stand Evaluator's file naming conventions are designed to allow a user to know beforehand the names of all files that will be created in a run. In general, Stand Evaluator programs form output file names by concatenation of input file names, codes supplied in the control files, and mnemonic extensions. This file naming convention was added to the CACTOS and CRYPTOS growth models, allowing complete tracking of the process used to develop an output file. For example, a log list file with the name "S1RX2L3.LOG" could indicate that this file represents stand type one, managed under prescription two, and bucked according to rule three. File name formation in all programs is controlled by the same easily modified subprogram code.

A key feature of the Stand Evaluator's design is the preservation of intermediate results at each stage at the most detailed level practical, in a compact standardized file format. Preservation of detail allows for more rigorous model validation, and permits summarization in a form appropriate for a particular application. At the outset of the design process, the importance of preservation of detail was hammered home when the CACTOS/CRYPTOS output format had to be revised to preserve tree level data. All Stand Evaluator intermediate files are binary, fixed logical record length files that conform to IEEE standards for representation of data (e.g. 4-byte integer, 4-byte reals). This

file structure was selected for several reasons: (1) it is compact, containing only data (i.e., no end-of-record characters or blanks), (2) it allows for rapid unformatted access, (3) it preserves precision, (4) it is suitable for direct access rapid processing when partial information retrieval is desired, and (5) it can be read by programs written in any language that conforms to the IEEE standards for data representation. Data content is also standardized for all Stand Evaluator intermediate files. Each file has 100 records for header information, allowing the user (and the programs) to store information in dedicated locations. Header information stored in input files is consistently preserved in the associated output files. Following the header, files contain consecutive sets of summary and detailed data records for each growth period and stand entry. The summary indicates the type of entry and the number of records contained in the entry.

A final significant design feature of the Stand Evaluator is reliance on users to provide the final link to their particular decision making model. The system is complete only for those clients using heuristic scheduling systems such as "cut the stands with the highest present net value." Rather than attempting to provide output formats suitable for all decision making models, we identified common processing requirements and designed a system that would meet them, leaving the final data summarization and organization to user designed programs that would meet specialized needs.

Application/Evaluation

Final evaluation of the Stand Evaluator's design depends upon our client's ability to integrate the Evaluator into their own information processing and decision making systems. This section discusses applications in progress or completed since the Stand Evaluator's release to the clients at the beginning of 1988.

Figure 3 depicts an application of the Evaluator by a client using a heuristic sale scheduling model. This client is essentially using the Evaluator as an off-the-shelf system, processing plot data through CACTOS, CTLAVG, LGBUCK, LOGVAL, and RPTWRT in that sequence, and using the economic summary report to rank stand for harvesting according to present net value, total merchantable volume, and current growth rate. This particular client is moving towards more sophisticated analyses, but even their current implementation of the Evaluator represents a significant improvement over the stand type map/ pickup truck method previously used.

Figure 4 represents an application currently under develop ment by Professor Richard Barber (Humboldt State Universit for the California Department of Forestry and Fire Protectio The application involves the use of the Stand Evaluator provide a link between an inventory system, CRYPTOS, and binary search model for short- and long-term manageme planning. The path taken through the Stand Evaluator uses a programs for the short-term model, but bypasses YDSPLT f the long-term model. RPTWRT's output writing subprogram being modified to produce output suitable for input to the binai search model. This application is also using LGBUCK develop gross-to-net volume conversion factors based on sca data.

Figure 5 represents the most sophisticated applications y carried out by one of our clients. CTLAVG and LGBUCK we used in developing a two-stage, planning model on a mainfran computer for a timber company selling logs. A geograph information, data base management system was first used develop average stand descriptions. These files were simulate in CACTOS under several management prescriptions, and the processed through LGBUCK. The LGBUCK program w modified to utilize taper equations developed by the client. user designed program summarized yields by species and lo size as a FORPLAN yield file for a district-level short-ter timber sale scheduling model. Results from this model we used to retrieve multiple-plot stand descriptions by operati unit, for subsequent CACTOS simulation. The tree list we averaged by CTLAVG, processed by the modified LGBUC program, and formatted into a FORPLAN yield file for operating unit-level short-term harvest scheduling model.

At the University of California, we have developed application using CACTOS, CTLAVG, YDSPLT, ar LGBUCK to build a short-term, harvest scheduling demonstr tion model. FORPLAN is used for matrix generation. Yields a summarized by the DIB breaks that determine the path a l takes through a mill. The models run on a microcomputer, ar illustrates the use of an alternative programming langua (PASCAL) to process Stand Evaluator data files. We are al developing a microcomputer application that modifies Eval ator output for input into a spreadsheet-based sale scheduli system.

The variety of Stand Evaluator applications already deve oped is a direct result of Evaluator's design. Our clients have h no problems in carrying out the program modifications need to suit their application. Since the file naming conventions ha not been completely integrated into any client's system, jud ment on their usefulness is premature.

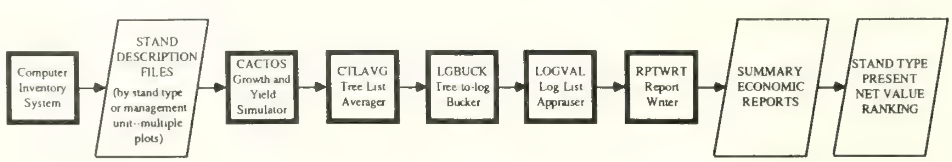

Figure 3.--Off-the-shelf application by a basic industrial user employing a heuristic forest management decision rule.

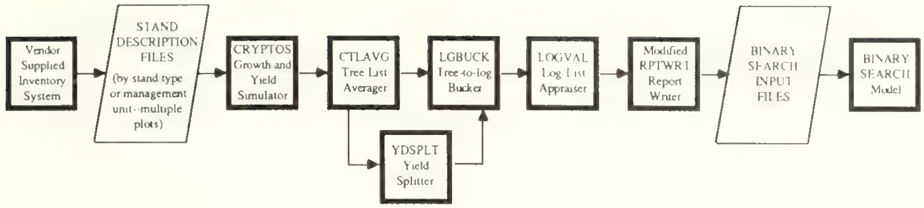

Figure 4.--Application under development by Richard Barber (Humboldt State University) for the California Department of Forestry and Fire Protection.

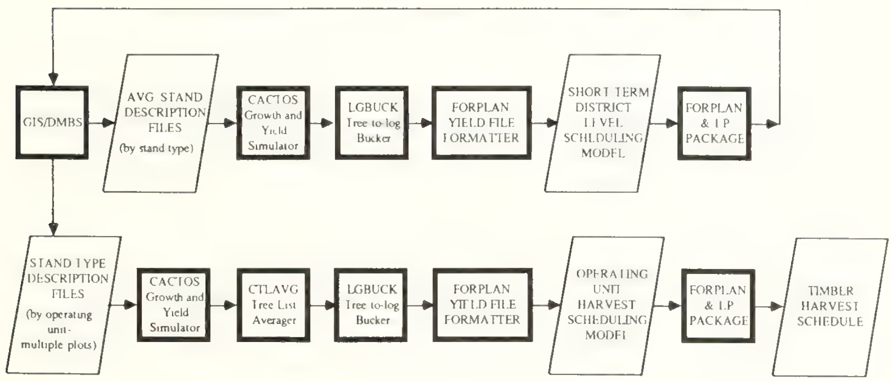

Figure 5.--Two-stage application developed by a sophisticated industrial client.

Several limitations on the implementation of the design criteria are known. Although structured programming conventions were followed, the time series character of CACTOS/CRYPTOS output files has made it difficult to add subprograms to the system for reading other sources of input data. One client found it easier to reformat their existing data on volume by log size and grade into our format than to develop a new LOGVAL input subprogram. Another limitation involves Evaluator data files. While these files conform to IEEE standards, the implementation of this standard varies between computer systems. As a result, intermediate data files are not directly transferable between systems. This problem was known early in the design process, and the decision was made that compactness and access speed was more important than intermediate data transfer between systems. A final limitation on the system is the system's steep learning curve. Our programming style has been nicknamed "user-hostile" because of the sophistication it assumes on the part of our clients. We make no apologies for this, since we consider flexibility and processing capability to be more important, and because of the steady growth in sophistication of the nonacademic forestry community.

Conclusions

The design process and final design of the Stand Evaluator raises some interesting issues in linking growth models and timber sale scheduling models for multiple clients. We have concluded that the system should be modular in design, allowing clients to use only those programs they need. Individual programs should focus on single, commonly needed functions, while the development of specialized applications should be left to individual clients. A standardized data file should be employed that preserves the intermediate results at a detailed level, to allow for validation and summarization at a later point. File handling conventions need to be flexible, yet standardized to allow for incorporation into existing systems. Programs should be written in a standard language to allow portability. Finally, coding should follow structured programming conventions to facilitate modification by clients.

The Stand Evaluator represents an attempt to meet these criteria and offers some questions that have yet to be resolved by forest system analysts. The requirement for standardized output raises the question whether as systems analysts we can agree upon standards to ensure compatibility of independently developed systems. The skill requirements to produce well structured program code raises the question as to whether nonprofessional programmers (i.e., most of us) should be writing code at all, or just designing the systems and hiring "real" programmers to generate the code. Finally, the release of source code to the clients, an inherent requirement of the Stand Evaluator's design, raises a number of touchy questions, regarding authorship credit, secondary distribution of the code, and compensation that need to be addressed by the forestry community's system analysts, academic and governmental research organizations, and forest industries.

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A Dynamic Programming Model for *Pinus hartwegii* in Central Mexico

Juan M. Torres-Rojo and J. Douglas Brodie[1]

Abstract.--A Dynamic Programming algorithm was incorporated to a growth and yield model to compute optimal thinning schedules. The algorithm optimizes timing, intensity, and type of thinning at different rotation ages.

A whole stand growth and yield model for *Pinus hartwegii* Lindl. was developed. Prediction equations are based on the compatible growth and yield prediction principle. Unit area yield estimates in the model are based on only four variables: basal area, number of trees per hectare, age, and site quality. A set of equations to describe the diameter distributions was adapted to the model. This set of equations predicts the parameters of a Weibull probability density function. By integrating the function over the desired class interval the frequencies for each class are estimated. Through this feature, the model is capable of predicting growth and yield after different intensities and thinning types are simulated.

The growth and yield model was then used as the basic production surface in a standard Dynamic Programming formulation to optimize thinning intensity, timing, type of thinning, and determine optimal rotation ages based on both soil expectation value and present net worth.

The optimizer consists of a Network whose nodes define different stand conditions at different periods. The optimization problem is defined as the maximization of the present net worth or soil expectation value over the rotation. The problem is formulated as a discrete time, discrete state Dynamic Programming problem. Forward recreation is used to identify the optimal treatment schedule.

The formulation does not require additional state variables to account for the thinning type optimization. It allows three thinning types, from below, from above and mechanical thinning.

The model can accept different pricing strategies for the harvested trees, i.e., it identifies different quality premiums. Thus the effect of having different monopsonistic buyers can be evaluated.

[1]Graduate student on leave from the National Institute of Forest Research, Mexico, and Professor, Department of Forest Management, College of Forestry, Oregon State University.

Queuing Simulation of Skidding Using XCELL+

Rakesh Gupta and Joseph P. Roise[1]

Abstract.--This paper describes an attempt to use XCELL+, a factory modeling software package, to simulate the use of skidder harvesting operations. XCELL+ is used to build a "logical model" of the production facility on a personal computer and to "run" that model to measure capacity and other production characteristics. Unlike the typical production system where the work center is static, the work center in this situation is dynamic.

The production of solid lumber, paper, and composite wood products is preceded by timber harvesting, the raw material delivery component of a wood production system. Steps involved in processing and movement of wood from stump to mill resembles those of other raw material extraction processes. Problems associated with production planning are similar for most raw material extraction operations. Raw material extraction is often characterized by relatively simple processing steps but complex material handling requirements. Extraction systems can be viewed as part of a factory, but with the dimensions of the factory changing with each new site. Managers and production planners must consider the variability introduced by changes in raw material characteristics, the general terrain of the area and the equipment available to move and process the raw material.

Machines used for harvesting wood are expensive, and thus, should be chosen for efficiency over a wide range of stand conditions. Fully mechanized logging has accomplished a considerable reduction in harvesting costs. This does not mean we should not strive for more efficient harvesting methods.

The traditional method used to select an optimal machine configuration has been the assembly line balancing method. Though an easy to use technique, it does not take into account interference between machines in the system. Queuing simulation, logical alternative, accounts for random interference. This paper emphasizes the interaction between machines in a system, as well as the production and utilization of individual machines. This analysis method provides the user the option to test alternative strategies for raw material extraction and to get an inexpensive understanding of a systems performance.

A queuing model approach which studies harvesting operation by simulation appears to be promising (Webster 1975). Simulation is a promising method for analyzing harvesting operations because timber harvesting systems have so many random variables as to defy systems analysis by any other method. Other techniques will not allow an analyst to take into account anywhere near the number of significant variables nor encompass the entire harvesting operation.

[1]*Department of Operation Research, Department of Forest Resources, North Carolina State University, Raleigh, NC.*

A simulation model is a mathematical model which imitates a real life process. This paper will describe a simple simulation model which enables us to study machine combinations for harvesting without recourse to expensive field trial. The discussion in this paper is directed toward an analysis of the major types of ground skidding timber harvesting operations used in southern bottomland hardwood sites.

MODEL OBJECTIVES

To use XCELL+, a factory modeling system, to simulate a typical forest harvesting operation. The specific objective are:

a. To develop a "logical model" of the operation on a personal computer.

b. To estimate production capacity, cost, and system bottlenecks.

c. To compare different machine systems and single out the best one.

XCELL+

XCELL+ is a computer application package that enables the construction of "logical models" of any production process. Simulation of production processes has been used with considerable success for many years. Without XCELL+, use of

simulation requires expertise in a specialized programming language. As a result, simulation was generally practiced by technical specialists, rather than by engineers and managers who are actually faced with the problem. Packages like XCELL+ represent a "spreadsheet approach" to simulation. XCELL+ can best be characterized as a "menu-driven system." That means that at each point in its use the possible actions are presented as a menu of choices. XCELL+ runs on personal computers, which adds to its appeal.

XCELL+ describes a factory floor as a uniform rectangular grid. Its intent is to represent only the logical relationship between elements, and it uses geometric representation only as a tool. The basic XCELL+ building block, are:

1. Workcenters--where Processes are run and work is performed.
2. Receiving areas--where material is received from the outside.
3. Buffers--where work-in-progress inventory is stored.
4. Shipping areas--from which finished material is shipped to the outside world.
5. Maintenance facility--where service teams are sent from to repair or provide scheduled maintenance for Workcenters.
6. Auxiliary resource--site from which resources are supplied to perform processes.
7. Control points--intersection of paths, and traffic control points in an asynchronous materials handling system.
8. Segment--of a path, connecting two control points, over which carriers can transport material.

In addition to these eight different types of elements, there are three other important design features:

1. Processes describes the work done at a workcenter. A particular workcenter can have many processes but only one can be active at a time.
2. Links describes the material flow to and from a process or a control point. A link can be regarded as an infinitely fast conveyor with no storage capacity.
3. Carriers are moving elements, superimposed on segments or control points, to carry loads over a materials handling network.

DATA COLLECTION AND ANALYSIS

The study was conducted on a site bordering the Pascagoula River in George County, Mississippi, owned by Scott Paper Company. The site was hand felled 1 week ahead of skidding. Three skidding systems with hauling distances of 0-1,500 feet were identified. Large and small rubber tired skidders were the CAT518 and CAT508. A crawler type skidder was a custom CATD5H. A brief description of the skidders follows.

CAT508 Grapple Skidder

The 508 is one of the caterpillars low power grapple skidders. It has a power rating of 95hp/75kw as compared to 130hp/97kw of CAT518. This skidder was fitted with a 28-inch rubber tire and a 82-inch grapple and shear. This skidder falls in the category of small skidder.

CAT518 Grapple Skidder

The horse power of this skidder is 130hp/97kw and falls in the category of large skidder. It was fitted with a 34-inch tire and a 100-inch grapple.

CATD5H Custom Grapple Skidder

This is considered to be a large track skidder. The horse power rating of this skidder is 120hp/89.5kw.

For the execution of the experiment, a three member data gathering crew was assigned to each machine system. The person in the woods recorded the start and end of the bunching process. The people at the landing were recording arrival, departure, and load characteristics. The species and number of trees per cycle were recorded by plot (skidding distance range) to measure production rate. Each log's length and diameter were recorded and the volume calculated using taper function tables (2). The skidders were harvesting tree length logs.

The plot was divided into four subplots with skidding distance ranges of 0-400 feet, 400-700 feet, 700-1,100 feet, and 1,100-1,500 feet. Following parameters were recorded to measure productivity.

Load Size

The load was measured in terms of three parameters:

a. Trees and Type (pine or hardwood)--each tree was numbered to measure skidder cycle and for truck load.
b. Tree length.
c. Tree diameter.

Time

A typical cycle consists of following elements:

a. Bunching time--starts the instant when the skidder picks up the first tree and ends with the instant the skidder picks the last.

Table 1.--Summary of time and motion study using three skidding systems.

Skidding distance	508		518		D5H	
(feet)	Mean	S.D.	Mean	S.D.	Mean	S.D.
			Cycle time (seconds)			
0-400	238.04	118.18	262.94	103.60	324.35	120.09
400-700	363.30	124.08	487.71	171.44	497.85	136.18
700-1,100	504.09	135.41	515.57	142.92	608.80	118.23
1,100-1,500	704.19	280.51	705.43	145.37	759.70	101.65
			Bunching time (seconds)			
0-400	80.18	53.72	91.57	56.89	152.37	97.66
400-700	118.32	62.93	198.44	141.87	249.13	120.47
700-1,100	162.00	98.50	209.15	109.45	240.25	123.74
1,100-1,500	186.19	141.94	280.00	124.44	242.80	107.13
			Travel loaded (seconds)			
1-400	86.76	62.49	85.03	50.48	75.21	49.3
400-700	163.19	97.35	205.39	59.11	107.00	30.06
700-1,100	165.78	63.98	199.58	42.23	173.84	53.66
1,100-1,500	236.41	80.17	247.64	66.47	245.04	43.89
			Travel unloaded (seconds)			
0-400	82.86	47.49	83.75	61.50	100.46	44.06
400-700	85.06	59.97	73.41	63.58	147.43	36.59
700-1,100	185.43	90.55	102.77	51.45	194.70	48.67
1,100-1,500	271.47	198.15	183.57	94.55	252.57	35.80

b. Travel loaded--starts when bunching ends and ends when the skidder drops the load at landing.

c. Travel unloaded--the time consumed by the skidder to travel from landing to the bunching site.

d. Downtime--accounts for any loss in time other than the normal course of activity. According to the Silviculture Equipment Handbook of the Government of Canada, the downtime can be of various types. A few of them were defined as:

   1. Active repair--repair constitute the mending or replacement of the part that has failed or has malfunctioned.

   2. Service--regular maintenance that a machine requires for its satisfactory operation.

3. Delay--time when the machine is not performing its primary function for reasons other than active repair and service.

DATA ANALYSIS

The data was analyzed using SAS, a statistical software package. Volume was calculated from large end diameter and height of the tree. Max and Burkhart's taper and volume functions were used (Martin 1981). Max and Burkhart's approach is to develop three separate submodels that describe the bole. The version selected for our study was their quadratic-quadratic-quadratic model.

Using SAS/BASE and SAS/STAT software, mean, standard deviation, and probability distribution were evaluated (SAS 1988). Tables 1 and 2 detail the elemental times and volume on a sub-plot basis for three different machine systems.

MODEL DEVELOPMENT

In a normal production system the work centers are static. This in not the case in harvesting. In harvesting the work center, skidder is dynamic. It moves from one location to another. To

Table 2.--Summary of time and volume data used in the model.

Skidding distance *(feet)*	Avg. processing time *(seconds)*	Average setup time *(seconds)*	Volume harvested *(cubic feet)*
CAT508			
0-400	3.36	1.70	3,990
400-700	5.19	1.30	3,542
700-1,100	5.03	2.75	3,953
1,100-1,500	6.53	4.33	4,738
CAT518			
0-400	2.68	1.39	2,797
400-700	6.30	1.11	1,296
700-1,100	5.26	1.41	2,987
1,100-1,500	5.75	1.93	2,218
CATD5H			
0-400	1.53	4.04	1,651
400-700	5.26	2.23	2,261
700-1,100	4.30	2.00	3,649
1,100-1,500	5.86	2.63	3,931

cope with this situation, we conceptualized the system as if the logs were dynamic and were flowing into the work center. So logs were dynamic and skidders were left static. This conceptualization allowed us to use XCELL+ modeling system.

Processing time at the work center is equal to the sum of travel loaded and bunching time. Setup time of skidder is equal to the travel unloaded part of cycle time. Using SAS programs, probability distribution and mean of these times for each machine is calculated. Table 3 details these times for each machine system. Both the processing and setup time are measured on a per unit volume of wood harvested.

The four subplots (0-400 feet, 400-700 feet, 700-1,100 feet, 1,100-1,500 feet) were simulated as receiving area. The inventory size for each receiving area was made equal to the volume harvested from that plot in the real experiment. Since the processing time and setup time increases as the skidding distance increases, the same skidder was modeled as four work centers each having different processing time and setup time. The landing is modeled as a buffer having finite capacity. The loader is simulated as another work center having a definite processing and setup time. Finally, the factory where logs are ultimately shipped is represented as a shipping area. The shipping area has unlimited capacity.

The flow of logs and the structural diagram is shown in figure 1. Logs flow from their respective receiving area into workcenters and then into the buffer (landing). When the landing reaches its capacity, the loader starts putting the logs on a truck or a forwarder, which carries them to the shipping area (factory). On work centers 2, 3, and 4, a lower trigger is implemented (i.e., work center 2 is triggered only when all logs have been removed from receiving area R1). All work centers operate sequentially in the order of WC1, followed by WC2, followed by WC3, and lastly WC4. The loader has a high trigger on it, which means it is active only when buffer (landing) reaches its capacity.

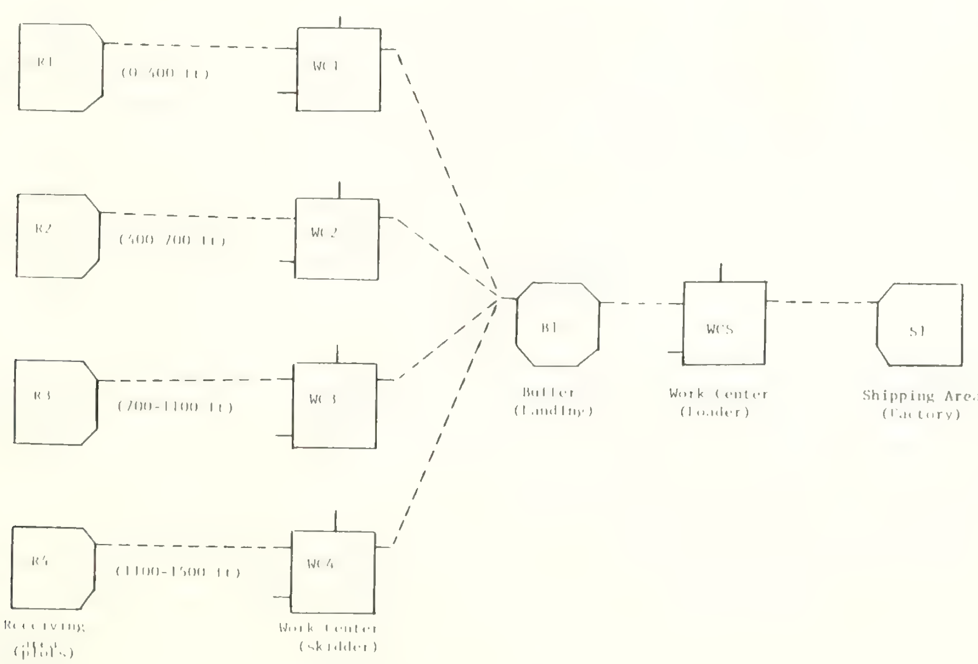

Figure 1.--Structural diagram of the model.

Table 3.--Summary of simulation results. Simulation was run until all volume was harvested.

Machine system	Throughput *(cubic feet)*	Cost unit/time	Work center utilization
CAT508	16,223	0.236	1.955
CAT518	9,298	0.132	1.048
CATD5H	11,492	0.165	1.356

RESULTS

Refer to table 3 for summary of simulation results. It can be seen that CAT518 comes out first with minimum cost/time. The work center utilization of CAT518 is minimum, followed by CATD5H and CAT508, respectively.

CONCLUSION

It can be concluded that use of XCELL+ is convenient and fast. Its use does not require any advance expertise in any particular programming language. This makes the tool particularly useful for managers and engineers to evaluate alternative strategies. The conceptual model of the production system is visible. There is no abstractness in the model, which is the case with most simulation languages. XCELL+ being menu driven is very easy to use.

Scope for Future Work

Future work will be in the following areas:

a. Modeling the trucking and forwarding operation.

b. Modeling that mixed species (like pine and hardwood) are harvested together but shipped separately.

c. Modeling the sorting of logs into saw logs and pulpwood either at the landing.

d. Inducing maintenance and associated downtime into the model.

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These proceedings contain the papers of the third symposium on systems analysis in forest resources management, held at Asilomar Conference Center, in Pacific Grove, Calif., in the spring of 1988. As with two previous meetings, a diverse and interesting group of papers was presented. General topic areas include land management planning, artificial intelligence, multicriteria optimization and fuzzy systems, regional timber supply analyses, stand level optimizations, and timber harvest scheduling.

Keywords: Land management planning, systems analysis, forest management, modeling, natural resource economics.

U.S. Department of Agriculture
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Rocky Mountains

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**Rocky Mountain
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**General Technical
Report RM-162**

Forest Vegetation on National Forests in the Rocky Mountain and Intermountain Regions: Habitat Types and Community Types

Robert R. Alexander

USDA Forest Service
General Technical Report RM-162

July 1988

Forest Vegetation on National Forests in the Rocky Mountain and Intermountain Regions: Habitat Types and Community Types

Robert R. Alexander, Chief Silviculturist
Rocky Mountain Forest and Range Experiment Station[1]

Abstract

Habitat types and community types and their phases for the major forest tree species in the Rocky Mountain and Intermountain regions are tabulated. Included are the name(s), general location, elevation, relative site, successional status, principal tree and undergrowth associates, and the authority.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Forest Vegetation on National Forests in the Rocky Mountain and Intermountain Regions: Habitat Types and Community Types

Robert R. Alexander

In 1985, a list was published that documented habitat types, community types, and plant communities in the Rocky Mountain and Intermountain regions in which interior *Pinus ponderosa*, interior *Pseudotsuga menziesii*, interior *Abies concolor*, *Picea pungens*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* occurred as either a major climax, co-climax, minor climax, or major seral species (Alexander 1985). This paper is intended to supplement the 1985 publication by including newly available data and data on phases omitted in the 1985 publication. Moreover, the habitat and community types in the series in which the naming species occurs, listed in the 1985 publication, are repeated for the readers convenience. In addition to the species listed above, forested habitat types and community types and their phases are included that are dominated by *Pinus leiophylla*, *Pinus engelmannii*, *Pinus strobiformis*, *Abies grandis*, *Thuja plicata*, *Tsuga heterophylla*, *Picea glauca*, *Pinus flexilis*, *Pinus aristata*, *Tsuga mertensiana*, *Pinus albicaulis*, and *Larix lyalli*. Woodland and riparian habitat types and community types are not included, because these classifications are incomplete.

Table A1 lists the identified habitat types and community types and their phases for all forest tree species in the Rocky Mountain and Intermountain regions. Also included are the general location, elevation, site, successional status, principal tree and undergrowth associates, and the authority for the classification.

Some of the terms used in the table are clarified as follows.

1. Habitat type is the basic unit in classifying lands based on potential (climax) natural vegetation. A "habitat type" represents, collectively, all parts of the landscape that support, or have the potential of supporting, the same climax vegetation. The climax vegetation upon which the classification is based is called a "plant association." The first level of the classification is the "series," which is the grouping of all plant associations having the same overstory (climax) dominants. For example, all habitat types with *Pinus leiophylla* as the potential climax dominant are grouped into the *Pinus leiophylla* series.

2. Habitat types within a series are distinguished on the basis of undergrowth unions, the smallest "structural unit" of the vegetation. Each union comprises one or more undergrowth species that exhibit similar microenvironmental requirements.

3. The term "community type" has been used to identify vegetation that may be either (1) climax, but about which there is uncertainty; (2) seral, but the trend toward climax is not evident; or (3) the recognized plant community in place, which varies at any given time. Community types have one or more overstory dominants and characteristic undergrowth species. The undergrowth may be climax, but the overstory dominants often are long-lived, seral species that may be self-perpetuating because of repeated disturbance that prevents or slows down the succession to climax vegetation.

4. The description of the site (e.g., warm dry, cool dry) refers only to the series and location and, therefore, is relative. Obviously, a warm dry *Pinus ponderosa* site is not the same as a warm dry *Abies lasiocarpa* site.

5. In those habitat types where more than one phase is recognized, the typic phase is listed first, followed by the other phases. Phase is a subdivision of a habitat type representing a characteristic variation in climax vegetation and environmental conditions.

6. Synonyms of habitat types and closely related habitat types (which may be the same habitat type) are included within brackets.

7. Under the heading "Principal undergrowth species," the undergrowth species for which the habitat type is named is listed first, followed in order by shrubs, graminoids, and forbs.

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Table A1.—Forest habitat types and community types in the Rocky Mountains.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
			Pinus leiophylla series			
Pinus leiophylla/ Arctostaphylos pungens C.T.	Mountains of south-central Arizona (5,200-7,100)	Hot very dry	*P. leiophylla* probably climax	*Juniperus deppeana*	*A. pungens* *Quercus* spp.	Muldavin et al. 1986
Pinus leiophylla/ Quercus arizonica H.T.	Mountains of south-central Arizona (4,900-7,100)	Hot very dry	*P. leiophylla* climax or co-climax with *Pinus ponderosa* *Pinus discolor* *J. deppeana*	*P. ponderosa* *P. discolor* *J. deppeana*	*Q. arizonica* *Arctostaphylos* spp. *Quercus hypoleucoides* *Rhus aromatica* *Muhlenbergia longiligula*	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pinus leiophylla/ Quercus emoryi H.T.	Mountains of south-central Arizona (4,900-6,500)	Hot very dry	*P. leiophylla* climax or co-climax with *P. discolor* *J. deppeana*	*P. discolor* *J. deppeana*	*Q. emoryi* *Q. arizonica* *Aristida orcuttiana* *Muhlenbergia* spp.	Muldavin et al. 1986
Pinus leiophylla/ Quercus hypoleucoides H.T.	Mountains of south-central Arizona (5,600-7,100)	Hot dry	*P. leiophylla* climax or co-climax with *P. discolor* *J. deppeana*	*P. discolor* *J. deppeana*	*Q. hypoleucoides* *Q. arizonica* *Muhlenbergia* spp.	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pinus leiophylla/ Quercus toumeyi H.T.	Mountains of south-central Arizona (5,500-6,500)	Hot very dry	*P. leiophylla* climax or co-climax with *P. discolor.* *J. deppeana* minor climax	*P. discolor* *J. deppeana*	*Q. toumeyi* *A. pungens*	DeVelice and Ludwig 1983
Pinus leiophylla/ Piptochaetium fimbriatum H.T. (Semi-riparian forest)	Mountains of south-central Arizona (5,000-6,000)	Hot moist	*P. leiophylla* climax or co-climax with *P. discolor* *J. deppeana*	*Pinus engelmannii* *P. discolor* *Cupressus arizonica* *J. deppeana* *Juniperus erythrocarpa*	*P. fimbriatum* *Juglans major* *Prunus serotina* *Q. arizonica* *Q. hypoleucoides*	DeVelice and Ludwig 1983 Muldavin et al. 1986
			Pinus engelmannii series			
Pinus engelmannii/ Quercus arizonica H.T.	Mountains of south-central Arizona (6,000-6,500)	Warm very dry	*P. engelmannii* climax or co-climax with *J. deppeana.* *P. discolor* minor climax	*P. leiophylla* *P. discolor* *J. deppeana*	*Q. arizonica* *M. longiligula*	DeVelice and Ludwig 1983
Pinus engelmannii/ Quercus emoryi H.T.	Mountains of southern Arizona (5,500-6,000)	Warm very dry	*P. engelmannii* climax	*P. leiophylla* *J. deppeana*	*Q. emoryi* *Muhlenbergia emersleyi* *M. longiligula*	Muldavin et al. 1986
Pinus engelmannii/ Quercus hypoleucoides H.T.	Mountains of south-central Arizona (5,800-7,100)	Warm dry	*P. engelmannii* climax. *P. discolor* *P. deppeana* minor climaxes	*P. leiophylla* *P. discolor* *J. deppeana*	*Q. hypoleucoides* *Q. arizonica* *M. longiligula*	DeVelice and Ludwig 1983 Muldavin et al. 1986

Muhlenbergia longiligula H.T.	south-central Arizona (6,500-7,000)		climax. *P. discolor* *J. deppeana* minor climaxes	*J. deppeana*	*Q. gambelii* *Q. hypoleucoides*	Ludwig 1983
			Pinus ponderosa series			
Pinus ponderosa/ Arctostaphylos patula H.T.	Mountains of southern Utah and western Colorado (7,500-8,500)	Warm very dry	*P. ponderosa* climax	*Pinus flexilis* *Juniperus scopulorum*	*A. patula* *Berberis repens* *Quercus gambelii* *Purshia tridentata* *Carex rossii*	Hoffman 1988 Youngblood and Mauk 1985
Pinus ponderosa/ Arctostaphylos pungens C.T. [*P. ponderosa/ Arctostaphylos* spp. C.T.] [*P. ponderosa*/Mixed chapparel C.T.]	Mountains of Arizona (5,000-7,600)	Warm very dry	*P. ponderosa* climax or co-climax with *J. deppeana*	*P. edulis* *J. deppeana*	*A. pungens* *Arctostaphylos* spp. *Cercocarpus montanus* *Quercus* spp. *Bouteloua gracilis* *Muhlenbergia virescens*	Fitzhugh et al. 1987 Hanks et al. 1983 Muldavin et al. 1986
Pinus ponderosa/ Arctostaphylos uva-ursi H.T.	Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (5,100-6,700); mountains of southeastern Wyoming (6,300-8,300), southern Colorado, and northern New Mexico (7,700-9,200)	Warm very dry	*P. ponderosa* climax. *P. menziesii* may be minor climax (CO,NM)	Usually pure stands (SD) *P. flexilis* *Populus tremuloides* (WY) *Pseudotsuga menziesii* (CO,NM)	*A. uva-ursi* *Symphoricarpos albus* *Festuca arizonica* *Muhlenbergia montana* *Carex* spp. *Arnica cordifolia* *Lathyrus ochroleucus* *Lupinus argenteus*	Alexander et al. 1986 DeVelice et al. 1986 Hoffman and Alexander 1987
Pinus ponderosa/ Artemisia nova H.T. [*P. ponderosa/ Artemisia arbuscula* H.T.]	Mountains of southern Utah (8,000-9,000), northern New Mexico, and southern Colorado (8,000-8,200)	Warm very dry	*P. ponderosa* climax (UT) or co-climax with *P. edulis* *J. scopulorum* (CO,NM)	*P. edulis* *P. flexilis* (UT) *J. scopulorum*	*A. nova* *A. arbuscula* *Chrysothamnus viscidiflorus* *Q. gambelii* *Tetradymia canescens* *B. gracilis*	DeVelice et al. 1986 Youngblood and Mauk 1985
Pinus ponderosa/ Cercocarpus ledifolius H.T.	Mountains of central and southern Utah (6,800-8,100)	Warm very dry	*P. ponderosa* climax. *J. scopulorum* minor climax	*P. edulis* *J. scopulorum*	*C. ledifolius* *A. tridentata* *Juniperus* spp. *Q. gambelii* *Symphoricarpos oreophilus*	Youngblood and Mauk 1985
Pinus ponderosa/ Cercocarpus montanus H.T. [*P. ponderosa/C. montanus-Rhus trilobata* H.T.]	Front Range, north-central Colorado (6,300-7,000)	Warm very dry	*P. ponderosa* climax	Usually pure stands. May contain *P. menziesii*	*C. montanus* *Opuntia polyacantha* *R. trilobata* *C. rossii* *Artemisia frigida* *Geranium fremontii*	Hess and Alexander 1986 Radloff 1983
Pinus ponderosa/ Cowania mexicana C.T.	Mountains of northern Arizona (6,700-7,500)	Warm very dry	*P. ponderosa* climax	Usually pure stands. May contain *P. edulis* *J. scopulorum*	*C. mexicana* *B. gracilis* *M. montana* *Sitanion hystrix*	Hanks et al. 1983
Pinus ponderosa/ Juglans major H.T. (Semi-riparian forest)	Mountains of south-central Arizona (5,500-6,500)	Warm moist	*P. ponderosa* climax	Usually pure stands	*J. major* *Agropyron* spp. *Panicum bulbosum* *Poa pratensis*	Muldavin et al. 1986

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pinus ponderosa/ Juniperus communis H.T.	Bighorn Mountains, north-central Wyoming; Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming; mountains of southwestern North Dakota and south-eastern Montana (4,000-6,300)	Warm dry to well-drained	*P. ponderosa* climax	Usually pure stands. May contain *P. tremuloides* *Quercus macrocarpa* (tree and/or shrub)	*J. communis* *B. repens* *Spiraea betulifolia* *S. albus* *Hesperochloa kingii* *P. pratensis* *Astragalus miser* *Clematis tenuiloba*	Hansen and Hoffman 1988 Hoffman and Alexander 1987
Pinus ponderosa- Juniperus scopulorum H.T. [*P. ponderosa-J. scopulorum/ Bouteloua curtipendula* H.T.]	Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (3,800-4,000)	Warm dry to well-drained	*P. ponderosa* climax to co-climax with *J. scopulorum*	*J. scopulorum*	*B. curtipendula* *Oryzopsis micrantha* *Anemone patens* *A. frigida* *Campanula rotundifolia*	Hoffman and Alexander 1987
Pinus ponderosa/ Physocarpus malvaceus H.T.	Mountains of northern and central Idaho and eastern Washington (<3,000)	Warm dry	*P. ponderosa* climax	Usually pure stands	*P. malvaceus* *Ceanothus sanguineus* *Holodiscus discolor* *Erythronium grandiflorum* *Galium boreale*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Steele et al. 1981
Pinus ponderosa/ Physocarpus monogynus H.T.	Bighorn Mountains, north-central Wyoming (6,100-6,600); Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (5,100-5,700)	Warm dry to well-drained	*P. ponderosa* climax	Usually pure stands. May contain *J. scopulorum*	*P. monogynus* *B. repens* *S. betulifolia* *S. albus* *Cystopteris fragilis* *G. boraele* *Solidago speciosa*	Hoffman and Alexander 1976, 1987
Pinus ponderosa/ Prunus virginiana H.T.(MT,ND); C.T.(SD) *P. virginiana* (typic) phase *Shepherdia canadensis* phase (MT)	Mountains of south-eastern Montana, southwestern North Dakota, and northern Black Hills, South Dakota (3,500-4,300)	Warm moist to well-drained	*P. ponderosa* climax	Usually pure stands	*P. virginiana* *Amelanchier alnifolia* *B. repens* *S. canadensis* *S. albus* *Arnica cordifolia* *C. fragilis*	Hansen and Hoffman 1988 Hoffman and Alexander 1987 Pfister et al. 1977
Pinus ponderosa/ Purshia tridentata H.T. *P. tridentata* (typic) phase *Agropyron spicatum* phase (ID,MT) *Festuca idahoensis* phase (ID,MT)	Mountains of Montana, northern and central Idaho, eastern Washington (3,000-6,000), and southern Utah (7,100-9,000); Front Range of north-central Colorado (7,600-8,700)	Warm dry	*P. ponderosa* climax. *J. scopulorum* minor climax	*P. menziesii* *J. scopulorum*	*P. tridentata* *A. tridentata* *P. virginiana* *A. spicatum* *Aristida longiseta* *F. idaoensis* *M. montana* *C. rossii* *Balsamorhiza sagittata*	Daubenmire and Daubenmire 1968 Hess and Alexander 1986 Pfister et al. 1977 Steele et al. 1981 Youngblood and Mauk 1985
Pinus ponderosa/ Quercus arizonica H.T.	Mountains of south-central	Hot dry	*P. ponderosa* climax or	*P. discolor* *J. deppeana*	*Q. arizonica* *Ceanothus fendleri*	DeVelice and Ludwig 1983

	Arizona (5,300-6,900)				*C. fendleri* *Garrya wrightii* *Q. arizonica*	[illegible]
Pinus ponderosa/ *Quercus gambelii* H.T. [*P. ponderosa-Pinus edulis/* *Q. gambelii* H.T.] [*P. ponderosa/Q. gambelii-* *Carex geyeri* H.T.] [*P. ponderosa/* *Poa fendleriana* C.T.] *Q. gambelii* (typic) phase *P. edulis* phase (AZ,CO,NM) *Symphoricarpos oreophilus* phase (CO,UT) *Bouteloua gracilis* phase (AZ,NM) *Festuca arizonica* phase (AZ,CO,NM) *Muhlenbergia longiligula* phase (AZ,NM) *Schizachyrium scoparium* phase (NM)	Mountains of southern Utah, Colorado, New Mexico, and south-central and eastern Arizona (6,500-9,200)	Warm dry	*P. ponderosa* climax or co-climax with *P. edulis.* *Pinus engelmannii* *J. deppeana* *Juniperus monosperma* *J. scopulorum* minor climaxes	*P. edulis* *P. menziesii* *P. discolor* *P. engelmannii* *J. deppeana* *J. monosperma* *Juniperus osteosperma* *J. scopulorum*	*Q. gambelii* *B. repens* *J. communis* *Rosa woodsii* *S. oreophilus* *B. gracilis* *F. arizonica* *Koeleria cristata* (*K. macrantha)* *Muhlenbergia* spp. *P. fendleriana* *S. scoparium* *C. geyeri* *Achillea lanulosa*	Alexander et al. 1984a, 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Hanks et al. 1983 Hess and Wasser 1982 Hoffman 1988 Muldavin et al. 1986 Youngblood and Mauk 1985
Pinus ponderosa/ *Quercus grisea* H.T. *Q. grisea* (typic) phase *Muhlenbergia longiligula* phase *Muhlenbergia montana* phase	Mountains of southwestern New Mexico and eastern Arizona (6,100-8,800)	Warm dry	*P. ponderosa* climax or co-climax with *P. edulis* *J. deppeana* *J. monosperma.* *P. menziesii* minor climax	*P. edulis* *P. menziesii* *J. deppeana* *J. monosperma*	*Q. grisea* *B. gracilis* *M. longiligula* *M. montana* *M. virescens* *P. fendleriana*	Fitzhugh et al. 1987
Pinus ponderosa/ *Quercus hypoleucoides* H.T.	Mountains of south-central Arizona (5,700-8,000)	Warm dry	*P. ponderosa* climax. *P. discolor* *Pinus engelmannii* *J. deppeana* minor climaxes	*P. engelmannii* *P. leiophylla* *P. discolor* *J. deppeana*	*Q. hypoleucoides* *C. fendleri* *G. wrightii* *Quercus* spp. *M. longiligula* *P. fendleriana*	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pinus ponderosa/ *Quercus macrocarpa* H.T.	Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (4,100-5,300)	Warm dry to well-drained	*P. ponderosa* climax	Usually pure stands	*Q. macrocarpa* *A. alnifolia* *B. repens* *Ostrya virginiana* *Elymus virginicus*	Hoffman and Alexander 1987
Pinus ponderosa/ *Quercus rugosa* H.T.	Mountains of south-central Arizona (7,000-8,800)	Warm moist to well-drained	*P. ponderosa* climax	Usually pure stands. May contain *Pinus strobiformis* *P. menziesii*	*Q. rugosa* *Quercus* spp.	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pinus ponderosa/ *Quercus undulata* H.T. *Q. undulata* (typic) phase *Muhlenbergia dubia* phase (NM) *Muhlenbergia longiligula* phase (NM)	Mountains of northern and southern New Mexico (6,500-8,000)	Hot dry	*P. ponderosa* climax or co-climax with *P. edulis.* *J. deppeana* *J. monosperma* *J. scopulorum* minor climaxes	*P. menziesii* *P. strobiformis* *P. edulis* *J. deppeana* *J. monosperma* *J. scopulorum*	*Q. undulata* *Q. arizonica* *Q. gambelii* *Andropogon* spp. *Bouteloua* spp. *M. dubia* *M. longiligula* *Artemisia ludoviciana*	Alexander et al. 1984a DeVelice et al. 1986
Pinus ponderosa/ *Ribes inerme* H.T. (Scree forest)	Mountains of northern New Mexico (7,500-8,500)	Cool dry	*P. ponderosa* climax	*P. menziesii* *P. edulis* *J. scopulorum* *J. deppeana*	*R. inerme* *Q. gambelii* *M. montana* *P. fendleriana*	DeVelice et al. 1986

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pinus ponderosa/ *Spiraea betulifolia* H.T.	Bighorn Mountains, north-central Wyoming (5,600-5,900)	Warm dry	*P. ponderosa* climax	Usually pure stands	*S. betulifolia* *C. tenuiloba* *S. albus* *F. idahoensis* *H. kingii* *G. boreale*	Hoffman and Alexander 1976
Pinus ponderosa/ *Symphoricarpos albus* H.T. *S. albus* (typic) phase *Berberis repens* phase (MT) *Oryzopsis asperifolia* phase (SD) *Balsamorhiza sagittata* phase (SD)	Mountains of eastern Washington, northern and central Idaho, and central and southeastern Montana (2,600-5,400); Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (4,200-6,000)	Warm dry	*P. ponderosa* climax	Usually pure stands. May contain *P. tremuloides* (SD,WY)	*S. albus* *B. repens* *J. communis* *P. virginiana* *Rosa* spp. *S. canadensis* *S. betulifolia* *O. asperifolia* *Carex foenea* *B. sagittata*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Hoffman and Alexander 1987 Pfister et al. 1977 Steele et al. 1981
Pinus ponderosa/ *Symphoricarpos oreophilus* H.T.	Mountains of central Idaho (≤5,000) and southern Utah (7,900-8,800)	Warm dry	*P. ponderosa* climax	Usually pure stands (ID). May contain (UT) *J. scopulorum* *P. tremuloides*	*S. oreophilus* *A. alnifolia* *B. repens* *P. virginiana* *P. tridentata* *A. spicatum*	Steele et al. 1981 Youngblood and Mauk 1985
Pinus ponderosa/ *Agropyron spicatum* H.T.	Mountains of eastern Washington, Idaho, southeastern and west-central Montana, north-central Wyoming, and southwestern North Dakota (2,400-6,000)	Hot very dry	*P. ponderosa* climax. *J. scopulorum* may be minor climax	Usually pure stands. May contain *J. scopulorum*	*A. spicatum* *Artemisia* spp. *A. longiseta* *Bromus tectorum* *F. idahoenis* *Poa* spp. *B. sagittata* *Lomatium dissectum* *Melica bulbosa*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Hansen and Hoffman 1988 Hoffman and Alexander 1976 Pfister et al. 1977 Steele et al. 1981
Pinus ponderosa/ *Andropogon* spp. H.T.	Mountains of southeastern Montana (≤4,000)	Warm very dry	*P. ponderosa* climax. *J. scopulorum* minor climax	*J. scopulorum*	*A. gerardii* *A. scoparius*	Pfister et al. 1977
Pinus ponderosa/ *Bouteloua gracilis* H.T. *B. gracilis* (typic) phase *Pinus edulis* phase (AZ) *Artemisia tridentata* phase (AZ) *Quercus gambelii* phase (AZ) *Andropogon hallii* phase (AZ) *Schizachyrium scoparium* phase (NM) *Vitis arizonica* phase (AZ)	Mountains of Arizona and New Mexico (5,700-8,600)	Warm very dry	*P. ponderosa* climax or co-climax with *P. edulis* *P. discolor* *J. deppeana.* *J. monosperma* J. scopulorum minor climaxes	*P. edulis* *P. discolor* *J. deppeana* *J. monosperma* *J. scopulorum*	*B. gracilis* *A. tridentata* *Q. gambelii* *Q. grisea* *A. hallii* *M. longiligula* *P. fendleriana* *S. scoparium* *V. arizonica*	Alexander et al. 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Hanks et al. 1983 Muldavin et al. 1986
Pinus ponderosa/	Mountains of	Warm dry	*P. ponderosa*	*P. edulis*	*F. arizonica*	Alexander et al.

						1988 Radloff 1983
Pinus ponderosa/ *Festuca idahoensis* H.T. *F. idahoensis* (typic) phase *P. ponderosa* phase (ID) *Arctostaphylos patula* phase (UT) *Artemisia tridentata* phase (UT) *Festuca scabrella* phase (MT)	Mountains of eastern Washington, Idaho, central and southeastern Montana, northern Utah, north-central Wyoming (2,500-6,000), and south-central Colorado (8,800-9,300)	Warm dry	*P. ponderosa* climax	Usually pure stands. May contain (UT) *Pinus contora* *J. scopulorum* *P. tremuloides*	*F. idahoensis* *A. patula* *A. tridentata* *B. repens* *P. tridentata* *S. albus* *A. spicatum* *Calamagrostis rubescens* *F. scaberila* *Achillea millefolium* *B. sagittata*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Hansen and Hoffman 1988 Hoffman and Alexander 1976 Komarkova et al. 1988 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981
Pinus ponderosa/ *Hesperochloa kingii* H.T.	Mountains of north-central Colorado (7,300-8,400)	Warm dry	*P. ponderosa* climax	*P. menziesii* *P. flexilis*	*H. kingii* *R. cereum* *K. cristata* (*K. macrantha*) *Allium geyeri* *A. frigida* *G. fremontii* *Sedum stenopetalum*	Hess and Alexander 1986
Pinus ponderosa/ *Muhlenbergia montana* H.T. [*P. ponderosa-Pseudotsuga menziesii/ M. montana* H.T.] [*P. ponderosa/ Poa longiligula* C.T.]	Mountains of Arizona and New Mexico, central and southern Utah, and central and southern Colorado (6,800-8,800)	Warm dry	*P. ponderosa* climax. *P. edulis* *J. deppeana* minor climaxes	*P. menziesii* *P. edulis* *P. flexilis* *J. deppeana* *J. monosperma* *J. scopulorum*	*M. montana* *B. repens* *C. montanus* *Q. gambelii* *B. gracilis* *P. fendleriana* *P. longiligula* *S. hystrix* *Senecio neomexicanus* *Smilacina stellata* *Solidago canadensis* *Yucca glauca*	Alexander et al. 1987 DeVelice et al. 1986 Fitzhugh et al. 1987 Hanks et al. 1983 Hess and Alexander 1986 Muldavin et al. 1986 Radloff 1983 Youngblood and Mauk 1985
Pinus ponderosa/ *Muhlenbergia virescens* H.T. [*P. ponderosa/M. virescens-Festuca arizonica* H.T.] [*P. ponderosa/M. virescens-F. arizonica/ Bouteloua gracilis* C.T.] *M. virescens* (typic) phase *Quercus gambelii* phase *B. gracilis* phase (AZ) *F. arizonica* phase	Mountains of Arizona and southwestern New Mexico (6,800-9,300)	Warm dry	*P. ponderosa* climax. *P. edulis* *P. menziesii* *P. strobiformis* *Pinus engelmannii* *J. deppeana* minor climaxes	*P. edulis* *P. menziesii* *P. strobiformis* *P. engelmannii* *J. deppeana*	*M. virescens* *B. repens* *C. fendleri* *Quercus* spp. *B. gracilis* *F. arizonica* *M. montana* *P. fendleriana* *P. longiligula* *Carex* spp. *Senecio wootonii*	Alexander et al. 1987 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Hanks et al. 1983 Muldavin et al. 1986
Pinus ponderosa/ *Oryzopsis hymenoides* H.T. (Sand hills)	Mountains of northern New Mexico and southern Colorado (5,500-6,000)	Warm very dry	*P. ponderosa* climax. *J. monosperma* minor climax	*J. monosperma*	*Q. hymenoides* *C. montanus* *S. scoparium* *S. hystrix* *Heterotheca fulcrata*	DeVelice et al. 1986

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pinus ponderosa/ Poa pratensis H.T. [*Pinus ponderosa/* Riparian forest H.T.]	Mountains of southwestern and northern New Mexico and southern Colorado (6,000-8,500)	Warm moist	*P. ponderosa* climax	*Populus angustifolia* *Acer negundo*	*P. pratensis* *Alnus tenuifolila* *Q. gambelii* *Galium* spp. *Iris missouriensis* *Juncus* spp.	Alexander et al. 1987 DeVelice et al. 1986
Pinus ponderosa/ Stipa comata H.T.	Mountains of northern Idaho and eastern Washington (2,500-3,000)	Warm very dry	*P. ponderosa* climax	Usually pure stands	*S. comata* *A. longiseta* *Poa secunda* *Stipa* spp.	Daubenmire and Daubenmire 1968
Pinus ponderosa/ Stipa occidentalis H.T.	Mountains of central Idaho (3,500-4,800)	Warm very dry	*P. ponderosa* climax	Usually pure stands	*S. occidentalis* *P. tridentata* *Stipa thurberiana*	Steele et al. 1981
Pinus ponderosa/ Carex geyeri H.T.	Mountains of northern Utah (7,200-8,300), and south-eastern Wyoming (6,100-8,500)	Cool dry	*P. ponderosa* climax	*P. contorta* (UT) *P. tremuloides*	*C. geyeri* *B. repens* *Pachistima myrsinites* *Poa nervosa* *A. cordifolia*	Alexander et al. 1986 Mauk and Henderson 1984
Pinus ponderosa/ Carex heliophylla H.T.	Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (4,500-5,200); mountains of southwestern North Dakota and south-eastern Montana (3,900-4,000)	Warm very dry	*P. ponderosa* climax	Usually pure stands. May contain *J. scopulorum*	*C. heliophylla* *A. spicatum* *Danthonia spicata* *F. idahoensis* *P. pratensis* *Stipa* spp. *Aster ciliolatus* *Heterotheca villosa*	Hansen and Hoffman 1988 Hoffman and Alexander 1987
Pinus ponderosa/ Carex rossii H.T.	Front Range, north-central Colorado, and mountains of southeastern Wyoming (5,800-6,400)	Warm dry to well-drained	*P. ponderosa* climax	Usually pure stands. May contain *P. menziesii* (CO) *J. scopulorum*	*C. rossii* *J. communis* *K. cristata* (*K. macrantha)* *M. montana* *A. lanulosa*	Alexander et al. 1986 Hess and Alexander 1986
Pinus ponderosa/ Cinder Soils H.T.	Mountains of north-central and northwestern New Mexico (7,700-8,500)	Warm dry	*P. ponderosa* climax. *P. edulis* minor climax	*P. edulis*	*Q. gambelii* *R. cereum* *B. gracilis* *M. montana* *Lupinus* spp.	Alexander et al. 1987
Pinus ponderosa/ Rockland H.T.	Mountains of eastern Arizona, and northern and southwestern New Mexico (8,300-8,700)	Warm dry	*P. ponderosa* climax. *P. menziesii* *P. edulis* *J. deppeana* minor climaxes	*P. menziesii* *P. edulis* *P. strobiformis* *J. deppeana*	*Q. grisea* *Bouteloua* spp. *F. arizonica* *M. montana* *M. virescens* *Solidago* spp.	Alexander et al. 1987 Fitzhugh et al. 1987

Pinus strobiformis series

Acer glabrum H.T. *A. glabrum* (typic) phase *Pachistima myrsinites* phase (ID,WY) *Symphoricarpos oreophilus* phase (ID)	central and southeastern Idaho, northwestern Wyoming (4,800-8,300), and northern Utah (5,800-7,700)		climax	*P. ponderosa* *P. contorta* *P. flexilis* *J. scopulorum* *P. tremuloides*	*A. [illegible]* *P. myrsinites* *P. virginiana* *R. cereum* *S. oreophilus* *C. rubescens* *A. cordifolia*	Steele et al. 1981, 1983
Pseudotsuga menziesii/ Acer grandidentatum H.T.	Mountains of south-central Arizona (6,500-7,000)	Warm moist	*P. menziesii* climax	*P. ponderosa* *J. deppeana*	*A. grandidentatum* *Holodiscus dumosus* *Q. arizonica* *Q. hypoleucoides*	DeVelice and Ludwig 1983
Pseudotsuga menziesii/ Arctostaphylos patula H.T.	Mountains of central and southern Utah (7,200-8,700)	Warm dry	*P. menziesii* climax. *J. scopulorum* minor climax	*P. ponderosa* *P. flexilis* *J. scopulorum*	*A. patula* *B. repens* *Ceanothus martinii* *S. oreophilus*	Youngblood and Mauk 1985
Pseudotsuga menziesii/ Arctostaphylos uva-ursi H.T.	Mountains of central Montana (4,700-6,500), and south-western New Mexico (9,500-10,000)	Warm very dry	*P. menziesii* climax or co-climax with *P. strobiformis*	*P. strobiformis* (NM) *P. ponderosa* *P. flexilis* (MT) *P. tremuloides* (NM)	*A. uva-ursi* *A. spicatum* *B. ciliatus* *Festuca* spp. *M. montana* *B. sagittata* *Lithospermum ruderale* *Solidago spathulata*	Fitzhugh et al. 1987 Pfister et al. 1977
Pseudotsuga menziesii/ Berberis repens H.T. *B. repens* (typic) phase *Pinus ponderosa* phase (UT) *Juniperus communis* phase (ID,UT,WY) *Symphoricarpos oreophilus* phase (ID,UT,WY) *Carex geyeri* phase (ID,UT)	Mountains of central and southeastern Idaho (4,500-7,700), north-western Wyoming (5,700-8,500), and northern Utah (5,400-9,700); mountains of north-central Wyoming (7,000-8,500), and western Colorado (8,000-9,900)	Warm dry to well-drained	*P. menziesii* climax. *P. ponderosa* *P. contorta* *P. flexilis* minor climaxes	*P. ponderosa* *P. contorta* *P. flexilis* *A. grandis* (Not WY) *J. scopulorum* *P. tremuloides*	*B. repens* *J. communis* *P. myrsinites* *S. oreophilus* *C. geyeri* *C. rossii* *A. cordifolia* *Galium septentrionale* *Smilacina racemosa*	Hoffman 1988 Hoffman and Alexander 1976 Mauk and Henderson 1984 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Pseudotsuga menziesii/ Cercocarpus ledifolius H.T.	Mountains of southeastern and central Idaho, and Utah (6,000-8,100)	Warm dry	*P. menziesii* climax or co-climax with *P. ponderosa.* *P. flexilis* *J. scopulorum* minor climaxes	*P. ponderosa* *P. flexilis* *J. scopulorum* *P. tremuloides*	*C. ledifolius* *B. repens* *S. oreophilus* *A. spicatum* *A. cordifolia* *B. sagittata* *Crepis aluminata*	Mauk and Henderson 1984 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Pseudotsuga menziesii/ Cercocarpus montanus H.T.	Mountains of central and southern Utah (7,200-8,200)	Warm dry	*P. menziesii* climax. *P. edulis* *J. osteosperma* *J. scopulorum* minor climaxes	*P. edulis* *J. osteosperma* *J. scopulorum*	*C. montanus* *B. repens* *J. communis* *Shepherdia rotundifolia* *S. oreophilus*	Youngblood and Mauk 1985
Pseudotsuga menziesii/ Clematis pseudoalpina H.T.	Front Range, central Colorado (7,800-9,300)	Warm well-drained	*P. menziesii* climax	*P. ponderosa* *P. flexilis* *P. tremuloides*	*C. pseudoalpina* *J. communis* *Rosa* spp. *Calamagrostis purpurascens* *Carex* spp. *Fragaria* spp. *Saxifraga bronchialis* *Thalictrum fendleri* *Valeriana edulis*	Radloff 1983

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pseudotsuga menziesii/ Holodiscus dumosus H.T. (Scree forest)	Mountains of northern and southwestern New Mexico, and southern Colorado (9,600-9,900)	Warm dry	*P. menziesii* climax or co-climax with *P. strobiformis*	*P. strobiformis* *Abies lasiocarpa* *Picea engelmannii* *P. flexilis* *P. tremuloides*	*H. dumosus* *C. montanus* *Jamesia americana* *Ribes* spp. *Salix scouleriana* *S. oreophilus*	DeVelice et al. 1986 Fitzhugh et al. 1987
Pseudotsuga menziesii/ Jamesia americana H.T.	Front Range, north-central Colorado, and mountains of south-central Colorado (7,200-9,800)	Cool dry to well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *P. flexilis* *J. scopulorum*	*J. americana* *A. glabrum* *J. communis* *P. monogynus* *Fragaria ovalis (F. virginiana)* *Potentilla fissa*	Hess and Alexander 1986 Komarkova et al. 1988 Radloff 1983
Pseudotsuga menziesii/ Juniperus communis H.T.	Mountains of central and southwestern Montana (6,400-7,800), central Idaho, and north-western Wyoming (7,400-10,300)	Cool dry to exces-sively drained	*P. menziesii* climax	*P. contorta* *P. flexilis* *J. scopulorum*	*J. communis* *Juniperus horizontalis* *S. canadensis* *S. oreophilus* *A. cordifolia* *A. miser* *F. ovalis (F. virginana)*	Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ Linnaea borealis H.T. *L. borealis* (typic) phase *Symphoricarpos albus* phase (MT) *Vaccinium globulare* phase (MT) *Calamagrostis rubescens* phase (MT)	Mountains of central and northwestern Montana, and central Idaho (2,600-6,500)	Warm moist to well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *Larix occidentalis*	*L. borealis* *S. albus* *S. betulifolia* *V. globulare* *C. rubescens* *A. cordifolia*	Pfister et al. 1977 Steele et al. 1981
Pseudotsuga menziesii/ Pachistima myrsinites H.T. [*P. menziesii/P. myrsinites-Carex geyeri* H.T.]	Mountains of central and western Colorado (7,100-10,000)	Cool dry to well-drained	*P. menziesii* climax	*Picca engelmannii* *P. contorta* *P. tremuloides*	*P. myrsinites* *B. repens* *Q. gambelii* *S. oreophilus* *Vaccinium myrtillus* *C. geyeri* *A. cordifolia*	Hess and Wasser 1982 Hoffman and Alexander 1980, 1983 Komarkova et al. 1988
Pseudotsuga menziesii/ Physocarpus malvaceus H.T. *P. malvaceus* (typic) phase *Pseudotsuga menziesii* phase *Pinus ponderosa* phase (ID) *Pachistima myrsinites* phase (ID,WY) *Calamagrostis rubescens* phase (ID,MT) *Smilacina stellata* phase (ID)	Mountains of eastern Washington, Idaho, Montana (2,000-7,100), northwestern Wyoming (5,400-7,500), and Utah (5,000-9,100)	Cool moist to well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *P. flexilis* *L. occidentalis* *J. scopulorum* *P. tremuloides*	*P. malvaceus* *A. alnifolia* *B. repens* *H. discolor* *P. myrsinites* *S. albus* *C. rubescens* *C. geyeri* *A. cordifolia* *S. stellata*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Pseudotsuga menziesii/ Physocarpus monogynus H.T.	Mountains of northwestern and north-central Wyoming (6,100-6,600); Front Range	Warm well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *P. flexilis* *J. scopulorum*	*P. monogynus* *B. repens* *J. americana* *S. betulifolia* *S. oreophilus*	Hess and Alexander 1986 Hoffman and Alexander 1976 Steele et al. 1983

Arctostaphylos uva-ursi H.T.] *Pinus ponderosa/ Artemisia tridentata* H.T.]	(8,800-9,800)				*J. communis* *K. cristata (K. macrantha)* *C. foenea*	
Pseudotsuga menziesii/ Quercus arizonica H.T.	Mountains of south-central Arizona (5,800-7,000)	Warm very dry	*P. menziesii* climax or co-climax with *P. ponderosa*	*P. ponderosa* *P. discolor* *J. deppeana*	*Q. arizonica* *Q. gambelii* *Q. hypoleucoides* *M. longiligula*	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pseudotsuga menziesii/ Quercus gambelii H.T. *Q. gambelii* (typic) phase *Holodiscus dumosus* phase (NM) *Festuca arizonica* phase (NM) *Muhlenbergia virescens* phase (AZ,NM)	Mountains of New Mexico, Arizona, southern Utah, and southern Colorado (6,500-9,600)	Warm dry	*P. menziesii* climax or co-climax with *P. ponderosa* *P. strobiformis* *J. scopulorum* minor climaxes	*P. ponderosa* *P. strobiformis* *P. edulis* *Pinus engelmannii* *J. deppeana* *J. scopulorum*	*Q. gambelii* *H. dumosus* *P. myrsinites* *S. oreophilus* *F. arizonica* *M. montana* *M. virescens* *P. fendleriana* *C. rossii*	Alexander et al. 1984a, 1984b, 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Muldavin et al. 1986 Youngblood and Mauk 1985
Pseudotsuga menziesii/ Quercus hypoleucoides H.T.	Mountains of south-central and eastern Arizona, and southwestern New Mexico (6,600-8,600)	Warm dry to well-drained	*P. menziesii* climax or co-climax with *P. ponderosa*	*P. ponderosa* *P. strobiformis* *Pinus engelmannii* *P. discolor* *P. edulis* *Abies concolor*	*Q. hypoleucoides* *Agave* spp. *Q. arizonica* *Q. gambelii* *Q. rugosa* *Opuntia* spp. *M. longiligula* *P. fendleriana*	DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986
Pseudotsuga menziesii/ Quercus rugosa H.T.	Mountains of south-central Arizona (6,500-8,700)	Warm to well-drained	*P. menziesii* climax	*P. ponderosa* *P. strobiformis*	*Q. rugosa* *Q. hypoleucoides*	DeVelice and Ludwig 1983 Muldavin et al. 1986
Pseudotsuga menziesii/ Spiraea betulifolia H.T. *S. betulifolia* (typic) phase *Pinus ponderosa* phase (ID) *Calamagrostis rubescens* phase (ID,WY)	Mountains of central Montana, Idaho (3,300-8,100), and northwestern Wyoming (6,000-8,200)	Warm dry	*P. menziesii* climax	*P. ponderosa* *P. contorta* *P. flexilis*	*S. betulifolia* *A. alnifolia* *B. repens* *C. rubescens* *A. cordifolia* *F. ovalis (F. virginiana)*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ Symphoricarpos albus H.T. *S. albus* (typic) phase *Pinus ponderosa* phase (ID) *Agropyron spicatum* phase (MT) *Calamagrostis rubescens* phase (ID,MT)	Mountains of eastern Washington, Idaho, Montana (2,700-7,200), and northwestern Wyoming (5,700-7,400)	Warm dry	*P. menziesii* climax	*P. ponderosa* *P. contorta* *L. occidentalis* *P. tremuloides*	*S. albus* *P. virginiana* *Rosa* spp. *S. betulifolia* *A. spicatum* *C. rubescens* *Festuca* spp. *C. geyeri*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ Symphoricarpos oreophilus H.T.	Mountains of central Idaho, southwestern Montana, north-western Wyoming (4,500-8,300), northern and southern Utah, and central and southern Colorado (7,000-9,800)	Warm dry	*P. menziesii* climax. *P. ponderosa* *P. flexilis* *J. scopulorum* minor climaxes	*P. ponderosa* *P. contorta* *P. flexilis* *J. scopulorum* *P. tremuloides*	*S. oreophilus* *A. tridentata* *B. repens* *P. virginiana* *Ribes* spp. *H. kingii* *C. geyeri* *Stellaria jamesiana* *T. fendleri*	Hess and Wasser 1982 Komarkova et al. 1988 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood and and Mauk 1985

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pseudotsuga menziesii/ *Vaccinium caespitosum* H.T.	Mountains of northern and central Idaho, and west-central and northwestern Montana (2,500-6,400)	Warm moist	*P. menziesii* climax	*P. ponderosa* *P. contorta* *L. occidentalis*	*V. caespitosum* *A. uva-ursi* *L. borealis* *S. albus* *C. rubescens* *C. geyeri*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981
Pseudotsuga menziesii/ *Vaccinium globulare* H.T. *V. globulare* (typic) phase *Arctostaphylos uva-ursi* phase (MT) *Xerophyllum tenax* phase (MT)	Mountains of north-central Montana, and Idaho (4,300-7,400)	Cool dry	*P. menziesii* climax	*P. ponderosa* *P. contorta* *L. occidentalis*	*V. globulare* *A. uva-ursi* *C. geyeri* *A. cordifolia* *Osmorhiza chilensis* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ *Agropyron spicatum* H.T.	Mountains of central Montana, and northern and central Idaho (3,800-7,500)	Warm very dry	*P. menziesii* co-climax with *P. ponderosa*. *P. flexilis* *J. scopulorum* minor climaxes	*P. ponderosa* *P. flexilis* *J. scopulorum*	*A. spicatum* *A. tridentata* *F. idahoensis* *B. sagittata* *M. bulbosa*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981
Pseudotsuga menziesii/ *Bromus ciliatus* H.T.	Mountains of southwestern New Mexico (9,000-10,000)	Cool moist to wet	*P. menziesii* climax. *P. ponderosa* *P. strobiformis* minor climaxes	*P. ponderosa* *P. strobiformis* *P. tremuloides*	*B. ciliatus* *A. glabrum* *P. fendleriana* *Erigeron eximius* (*E. superbus*)	Alexander et al. 1987 Fitzhugh et al. 1987
Pseudotsuga menziesii/ *Calamagrostis rubescens* H.T. *C. rubescens* (typic) phase *Pinus ponderosa* phase (ID,MT) *Arctostaphylos uva-ursi* phase (ID,MT) *Pachistima myrsinites* phase (ID,WY) *Agropyron spicatum* phase (MT) *Festuca idahoensis* phase (ID)	Mountains of eastern Washington, Idaho, Montana, northern Utah (4,100-7,900), and northwestern Wyoming (6,000-8,100)	Cool dry to well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *P. flexilis* *L. occidentalis* *P. tremuloides*	*C. rubescens* *A. uva-ursi* *B. repens* *P. myrsinites* *A. spicatum* *F. idahoensis* *C. geyeri* *A. cordifolia* *Smilacina amplexicaulis*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ *Festuca arizonica* H.T.	Mountains of northern and southwestern New Mexico, eastern Arizona, and southern Colorado (8,200-10,000)	Warm dry	*P. menziesii* climax	*P. ponderosa* *P. strobiformis* *P. flexilis* *Pinus aristata* *P. edulis* *J. deppeana* *J. scopulorum* *P. tremuloides*	*F. arizonica* *A. uva-ursi* *H. dumosus* *Q. gambelii* *B. ciliatus* *K. cristata* (*K. macrantha*) *M. montana* *P. fendleriana*	Alexander et al. 1984b, 1987 DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Pseudotsuga menziesii/ *Festuca idahoensis* H.T. *F. idahoensis* (typic) phase *Pinus ponderosa* phase (ID)	Mountains of southwestern Montana, northern and central Idaho (3,000-8,000), and south-central	Warm dry	*P. menziesii* climax or co-climax with *P. ponderosa*	*P. ponderosa*	*F. idahoensis* *A. alnifolia* *P. virginiana* *Rosa* spp. *A. spicatum* *C. rubescens*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981 Komarkova et al. 1988

	Montana (2,700-7,400)		*P. flexilis* minor climax		*K. cristata* (*K. macrantha*) *B. sagittata*	
Pseudotsuga menziesii/ Muhlenbergia montana H.T.	Mountains of southwestern New Mexico and eastern Arizona (7,500-9,800)	Warm dry	*P. menziesii* climax or co-climax with *P. ponderosa*	*P. ponderosa* *P. strobiformis* *P. edulis* *J. deppeana* *J. monosperma* *J. scopulorum*	*M. montana* *B. repens* *Q. gambelii* *P. fendleriana* *Geranium caespitosum* *Lithospermum multiflorum*	Alexander et al. 1987 Fitzhugh et al. 1987
Pseudotsuga menziesii/ Muhlenbergia virescens H.T. [*P. menziesii- Pinus strobiformis/ M. virescens* H.T.]	Mountains of southwestern New Mexico and Arizona (7,800-9,400)	Warm dry	*P. menziesii* climax or co-climax with *P. ponderosa* *P. strobiformis*. *A. concolor* minor climax	*P. ponderosa* *P. strobiformis* *A. concolor* *J. deppeana* *P. tremuloides*	*M. virescens* *C. fendleri* *Q. gambelii* *B. ciliatus* *P. fendleriana* *C. rossii* *Geranium richardsonii* *F. ovalis* (*F. virginiana*)	Alexander et al. 1984b DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986
Pseudotsuga menziesii/ Carex geyeri H.T. *C. geyeri* (typic) phase *Pinus ponderosa* phase (ID) *Symphoricarpos oreophilus* phase (ID)	Mountains of Montana east of Continental Divide (6,100-7,600) and northern and central Idaho (3,700-8,700); Front Range and mountains of south-central Colorado (7,800-8,800)	Cool dry	*P. menziesii* climax	*P. ponderosa* *P. contorta* *L. occidentalis* *J. scopulorum* *P. tremuloides* (CO)	*C. geyeri* *A. uva-ursi* *P. virginiana* *S. oreophilus* *A. spicatum* *A. lanulosa* *A. cordifolia* *Fragaria* spp.	Cooper et al. 1987 Hess and Alexander 1986 Komarkova et al. 1988 Pfister et al. 1977 Steele et al 1981
Pseudotsuga menziesii/ Carex rossii H.T.	Front Range of north-central Colorado (5,800-6,200)	Warm dry to well-drained	*P. menziesii* climax	*P. ponderosa* *J. scopulorum*	*C. rossii* *J. communis* *P. monogynus* *A. lanulosa* *C. rotundifolia* *C. fragilis*	Hess and Alexander 1986
Pseudotsuga menziesii/ Arnica cordifolia H.T. *A. cordifolia* (typic) phase *Astragalis miser* phase (ID)	Mountains of central and southwestern Montana, central and southeastern Idaho (5,900-8,600), and northwestern Wyoming (6,900-9,500)	Cool dry	*P. menziesii* climax	*P. contorta* *P. flexilis* *J. scopulorum*	*A. cordifolia* *B. repens* *J. communis* *S. oreophilus* *F. idahoensis* *P. nervosa* *A. miser* *Thalictrum occidentale*	Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii/ Osmorhiza chilensis H.T.	Mountains of central and southeastern Idaho, and northern Utah (5,300-7,800)	Warm moist to well-drained	*P. menziesii* climax	*P. ponderosa* *P. contorta* *A. grandis* *J. scopulorum* *P. tremuloides*	*O. chilensis* *P. myrsinites* *P. virginiana* *C. rubescens* *A. cordifolia* *S. racemosa* *Viola nuttallii*	Mauk and Henderson 1984 Steele et al. 1981, 1983
Pseudotsuga menziesii/ Sparse H.T. [*P. menziesii/ Berberis repens* H.T.]	Mountains of north-central Arizona (7,000-8,500)	Warm dry	*P. menziesii* climax	*P. ponderosa* *P. strobiformis*	*B. repens* *Bromus richardsonii* *P. fendleriana* (undergrowth sparse)	Alexander et al. 1984b

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
			Abies concolor series			
Abies concolor/ *Acer glabrum* H.T. [*A. concolor-* *Pseudotsuga menziesii/* *A. glabrum* H.T.] *A. glabrum* (typic) phase *Berberis repens* phase (AZ,NM) *Holodiscus dumosus* phase (AZ,NM) *Pachistima myrsinites* phase Riparian phase (NM)	Mountains of New Mexico, Arizona, southern Colorado (8,000-9,800), and southern Utah (7,400-8,400)	Cool moist to well-drained	*A. concolor* co-climax with *P. menziesii.* *Picea engelmannii* *Picea pungens* *P. ponderosa* *P. strobiformis* minor climaxes in some phases	*P. menziesii* *P. pungens* *P. engelmannii* *P. strobiformis* *P. ponderosa* *P. flexilis* *P. tremuloides*	*A. glabrum* *A. alnifolia* *A. tenuifolia* *B. repens* *H. dumosus* *P. myrsinites* *P. virginiana* *Q. gambelii* *B. ciliatus* *G. richardsonii* *S. amplexicaulis* *T. fendleri*	Alexander et al. 1984a, 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986 Youngblood and Mauk 1985
Abies concolor/ *Acer grandidentatum* H.T. *A. grandidentatum* (typic) phase *Holodiscus dumosus* phase	Mountains of south-central and eastern Arizona, and southwestern New Mexico (6,500-8,500)	Warm moist to well-drained	*A. concolor* climax or co-climax with *P. menziesii.* *P. engelmannii* *P. strobiformis* minor climaxes	*P. menziesii* *P. engelmannii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*A. grandidentatum* *H. dumosus* *J. major* *Q. gambelii* *C. foenea* *T. fendleri* *Viola canadensis*	Alexander et al. 1984a DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986
Abies concolor/ *Arctostaphylos patula* H.T.	Mountains of southern Utah (8,100-8,500)	Warm dry	*A. concolor* climax	*P. menziesii* *P. pungens* *P. ponderosa* *P. flexilis* *Pinus longaeva* *J. scopulorum*	*A. patula* *B. repens* *J. communis* *P. tridentata* *Q. gambelii* *S. oreophilus*	Youngblood and Mauk 1985
Abies concolor/ *Arctostaphylos uva-ursi* H.T.	Mountains of northern New Mexico and southern Colorado (7,900-9,500)	Cool dry	*A. concolor* co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. flexilis* *P. tremuloides*	*A. uva-ursi* *P. myrsinites* *J. communis* *F. ovalis* (*F. virginiana*)	DeVelice et al. 1986
Abies concolor/ *Berberis repens* H.T. *B. repens* (typic) phase *Juniperus communis* phase *Symphoricarpos oreophilus* phase	Mountains of Utah (5,700-9,600)	Cool dry	*A. concolor* climax	*P. menziesii* *P. pungens* *A. grandis* *P. ponderosa* *P. contorta* *P. flexilis* *P. tremuloides*	*B. repens* *J. communis* *P. mrysinites* *R. woodsii* *S. oreophilus* *Lathyrus leucanthus* *Osmorhiza* spp.	Mauk and Henderson 1984 Youngblood and Mauk 1985
Abies concolor/ *Cercocarpus ledifolius* H.T.	Mountains of central and southern Utah (7,000-9,400)	Warm dry	*A. concolor* climax	*P. menziesii* *P. ponderosa* *P. flexilis* *J. scopulorum*	*C. ledifolius* *A. alnifolia* *B. repens* *Q. gambelii* *S. oreophilus*	Youngblood and Mauk 1985
Abies concolor/ *Holodiscus dumosus* H.T. (Scree forest)	Mountains of northern and southwestern southern Colorado	Cool dry	*A. concolor* co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*H. dumosus* *J. americana* *Ribes* spp. [illegible]	DeVelice et al. 1986 Fitzhugh et al. [illegible]

	central Arizona (6,500-7,000)		minor climax	*P. angustifolia* *Fraxinus pennsylvanica* *A. negundo*	*Galium mexicanum* *T. fendleri* *V. arizonica*	1987 Muldavin et al. 1986
Abies concolor/ *Juniperus communis* H.T.	Mountains of southern Utah (7,000-9,000)	Cool dry	*A. concolor* climax	*P. menziesii* *P. pungens* *P. flexilis* *J. scopulorum* *P. tremuloides*	*J. communis* *B. repens* *R. woodsii* *S. oreophilus* *C. rossii*	Youngblood and Mauk 1985
Abies concolor/ *Physocarpus malvaceus* H.T.	Mountains of Utah (5,000-7,000)	Warm moist	*A. concolor* climax or co-climax with *P. menziesii*	*P. menziesii* *A. grandis* *J. scopulorum* *P. tremuloides*	*P. malvaceus* *A. alnifolia* *Q. gambelii* *S. oreophilus* *Mitella stauropetala* *S. racemosa*	Mauk and Henderson 1984 Youngblood and Mauk 1985
Abies concolor/ *Quercus gambelii* H.T. [*A. concolor-* *Pseudotsuga menziesii/* *Q. gambelii* H.T.] *Q. gambelii* (typic) phase *Holodiscus dumosus* phase (NM) *Festuca arizonica* phase (AZ,NM) *Muhlenbergia dubia* phase (NM) *Muhlenbergia virescens* phase (AZ,NM)	Mountains of New Mexico, Arizona, Utah, and southern Colorado (6,500-9,500)	Warm dry to well- drained	*A. concolor* co-climax with *P. menziesii.* *P. ponderosa* *P. strobiformis* minor climaxes in some phases	*P. menziesii* *P. ponderosa* *P. strobiformis* *P. flexilis* *P. engelmannii* *J. deppeana* *J. scopulorum* *P. tremuloides*	*Q. gambelii* *B. repens* *H. dumosus* *S. oreophilus* *F. arizonica* *M. dubia* *M. virescens* *Lathyrus arizonicus* *T. fendleri*	Alexander et al. 1984a, 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986 Youngblood and Mauk 1985
Abies concolor/ *Robinia neomexicana* H.T.	Mountains of eastern Arizona and southwestern New Mexico (8,500-9,000)	Warm dry	*A. concolor* co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*R. neomexicana* *Q. gambelii* *Rubus* spp. *C. foenea* *G. richardsonii*	Fitzhugh et al. 1987 Moir and Ludwig 1979
Abies concolor/ *Symphoricarpos oreophilus* H.T.	Mountains of central and southern Utah (6,800-9,300)	Warm dry to well- drained	*A. concolor* climax	*P. menziesii* *P. ponderosa* *J. scopulorum* *P. tremuloides*	*S. oreophilus* *A. alnifolia* *R. woodsii* *P. fendleriana* *C. rossii*	Youngblood and Mauk 1985
Abies concolor/ *Vaccinium myrtillus* H.T.	Mountains of northern New Mexico and southern Colorado (8,500-9,200)	Cool dry	*A. concolor* co-climax with *P. menziesii.* *A. lasiocarpa* *P. engelmannii* *P. pungens* minor climaxes	*P. menziesii* *A. lasiocarpa* *P. pungens* *P. engelmannii* *P. ponderosa* *P. flexilis* *P. tremuloides*	*V. myrtillus* *A. glabrum* *A. alnifolia* *A. uva-ursi* *B. repens* *P. myrsinites* *Rubus parviflorus*	DeVelice et al. 1986
Abies concolor/ *Elymus triticoides* H.T. [*A. concolor-* *Pseudotsuga menziesii/* *E. triticoides* H.T.]	Mountains of southern New Mexico (7,500-9,500)	Warm dry to well- drained	*A. concolor* co-climax with *P. menziesii.* *P. strobiformis* minor climax	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*E. triticoides* *H. dumosus* *Q. gambelii* *B. richardsonii* *M. montana*	Alexander et al. 1984a Moir and Ludwig 1979
Abies concolor/ *Festuca arizonica* H.T. [*A. concolor-* *Pseudotsuga menziesii/* *Poa fendleriana* H.T.] *F. arizonica* (typic) phase *Quercus gambelii* phase *P. fendleriana* phase	Mountains of eastern Arizona, and northern and southwestern New Mexico (8,200-10,200)	Warm dry	*A. concolor* climax or co-climax with *P. menziesii* *P. flexilis*	*P. menziesii* *P. flexilis* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*F. arizonica* *Q. gambelii* *M. montana* *P. fendleriana* *Erigeron* spp. *Fragaria vesca* (*F. americana*)	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Abies concolor/ Muhlenbergia virescens H.T.	Mountains of eastern Arizona and southwestern New Mexico (8,000-9,200)	Warm dry	*A. concolor* co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*M. virescens* *Q. gambelii* *B. ciliatus* *P. fendleriana* *C. rossii* *L. arizonicus* *Senecio* spp.	Fitzhugh et al. 1987
Abies concolor/ Carex foenea H.T.	Mountains of eastern and south-central Arizona (8,600-9,500)	Warm moist to well-drained	*A. concolor* climax	*P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*C. foenea* *B. ciliatus* *P. pratensis* *G. richardsonii* *Fragaria* spp.	DeVelice and Ludwig 1983 Moir and Ludwig 1979 Muldavin et al. 1986
Abies concolor/ Erigeron eximius H.T. [*A. concolor-Pseudotsuga menziesii E. superbus* H.T.]	Mountains of northern and southwestern New Mexico, south-central and eastern Arizona, and Colorado (8,500-9,800)	Cool moist	*A. concolor* co-climax with *P. menziesii*. *P. engelmannii* *P. pungens* minor climaxes	*P. menziesii* *P. engelmannii* *P. pungens* *P. ponderosa* *P. strobiformis* *P. flexilis* *P. tremuloides*	*E. eximius* (*E. superbus*) *B. ciliatus* *C. foenea* *F. ovalis* (*F. virginiana*) *H. parryi* *L. arizonicus*	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986
Abies concolor/ Galium triflorum H.T. (Riparian forest)	Mountains of northern New Mexico and southern Colorado (7,500-9,000)	Cool moist	*A. concolor* climax	*P. menziesii* *J. scopulorum* *P. angustifolia*	*G. triflorum* *A. glabrum* *A. tenuifolia* *P. virginiana* *Q. gambelii* *P. pratensis* *T. fendleri*	DeVelice et al. 1986
Abies concolor-Pseudotsuga menziesii/ Lathyrus arizonicus **H.T.**	Mountains of north-central Arizona (8,000-10,000)	Cool dry	*A. concolor* co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides*	*L. arizonicus* *B. repens* *G. richardsonii*	Moir and Ludwig 1979
Abies concolor/ Osmorhiza chilensis H.T.	Mountains of northern Utah (5,400-7,000)	Warm moist to well-drained	*A. concolor* climax	*P. menziesii* *A. grandis* *P. engelmannii* *P. tremuloides*	*O. chilensis* *A. alnifolia* *P. malvaceus* *P. myrsinites* *P. virginiana*	Mauk and Henderson 1984
Abies concolor/ Sparse H.T. [*A. concolor-Pseudotsuga menziesii* H.T.] ***Berberis repens*** **phase** ***Robinia neomexicana*** **phase**	Mountains of northern and southwestern New Mexico, south-central and eastern Arizona, and southern Colorado (8,000-9,800)	Cool dry	*A. concolor* co-climax with *P. menziesii*. *P. pungens* *P. engelmannii* minor climaxes	*P. menziesii* *P. pungens* *P. engelmannii* *P. ponderosa* *P. strobiformis* *P. flexilis* *P. aristata* *P. tremuloides*	*S. oreophilus* *B. repens* *Q. gambelii* *R. neomexicana* *B. ciliatus* (undergrowth sparse)	Alexander et al. 1984a DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Moir and Ludwig 1979 Muldavin et al. 1986

Amelanchier alnifolia H.T. (Riparian forest) [*P. pungens/A. alnifolia-Cornus stolonifera/ Carex geyeri* H.T.] [*P. pungens/Alnus tenulifolia* HT]	central and western Colorado (6,600-8,500)		climax	*A. lasiocarpa* *P. ponderosa* *P. tremuloides* *P. angustifolia*	*A. tenuifolia* *C. stolonifera* (*Swida sericea*) *R. woodsii* *Festuca thurberi* *C. geyeri*	1982 Hoffman 1988 Komarkova et al. 1988
Picea pungens/ Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico (7,900-9,200)	Warm dry	*P. pungens* co-climax with *P. menziesii* *A. concolor*	*P. menziesii* *A. concolor* *P. ponderosa* *P. flexilis* *P. tremuloides*	*A. uva-ursi* *J. communis* *B. ciliatus* *F. ovalis* (*F. virginiana*) *S. stellata*	DeVelice et al. 1986
Picea pungens/ Berberis repens H.T. *B. repens* (typic) phase *Symphoricarpos oreophilus* phase	Mountains of Utah (7,800-9,000)	Cool dry	*P. pungens* climax. *P. menziesii* minor climax	*P. menziesii* *P. contorta* *P. ponderosa* *P. flexilis* *J. scopulorum* *P. tremuloides*	*B. repens* *J. communis* *P. myrsinites* *Ribes montigenum* *S. oreophilus* *Aquilegia caerulea* *Pyrola secunda*	Mauk and Henderson 1984 Pfister 1972 Youngblood and Mauk 1985
Picea pungens/ Cornus stolonifera H.T. [*P. pungens/ Swida sericea* H.T.] (Riparian forest)	Mountains of northern and southwestern New Mexico, and southern Colorado (7,500-9,200)	Warm moist	*P. pungens* co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. tremuloides* *P. angustifolia*	*C. stolonifera* (*S. sericea*) *A. glabrum* *A. tenuifolia* *B. repens* *Salix* spp. *Calamagrostis canadensis* *C. foenea* *G. triflorum* *G. richardsonii* *S. stellata*	Alexander et al. 1987 DeVelice et al. 1986
Picea pungens/ Juniperus communis H.T.	Mountains of central Utah (8,000-8,600)	Cool dry	*P. pungens* climax	*P. menziesii* *P. ponderosa* *P. flexilis* *J. scopulorum* *P. tremuloides*	*J. communis* *A. uva-ursi* *B. repens* *P. myrsinites* *S. oreophilus*	Youngblood and Mauk 1985
Picea pungens/ Linnaea borealis H.T. [*P. pungens-Pseudotsuga menziesii* H.T. *L. borealis* phase]	Mountains of northern New Mexico and southern Colorado (8,200-9,200)	Cool moist to well-drained	*P. pungens* co-climax with *P. menziesii* *A. concolor.* *A. lasiocarpa* *P. engelmannii* minor climaxes	*P. menziesii* *A. concolor* *A. lasiocarpa* *P. engelmannii* *P. strobiformis* *P. flexilis* *P. tremuloides*	*L. borealis* *P. myrsinites* *R. parviflorus* *V. myrtillus* *C. foenea* *E. eximius* (*E. superbus*)	DeVelice et al. 1986 Moir and Ludwig 1979
Picea pungens/ Agropyron spicatum H.T.	Mountains of northern Utah (7,800-8,800)	Warm very dry	*P. pungens* climax	*P. menziesii* *P. contorta* *P. ponderosa* *P. flexilis* *J. scopulorum* *P. tremuloides*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites* *S. oreophilus* *A. cordifolia*	Mauk and Henderson 1984
Picea pungens/ Festuca arizonica H.T. [*P. pungens/Carex foenea* H.T. *Pinus ponderosa* phase]	Mountains of northern and south-western New Mexico, eastern Arizona, and southern and western Colorado (8,200-9,800)	Warm dry	*P. pungens* climax (CO) or co-climax with *P. menziesii* (AZ,NM). *A. concolor* *P. ponderosa* minor climaxes	*P. menziesii* *A. concolor* *P. ponderosa* *P. flexilis* *P. aristata* (CO) *P. tremuloides*	*F. arizonica* *C. foenea* *A. frigida* *Erigeron* spp. *Fragaria* spp. *L. arizonicus* *Senecio* spp.	DeVelice et al. 1986 Komarkova et al. 1988 Fitzhugh et al. 1987 Moir and Ludwig 1979

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Picea pungens/ Poa pratensis H.T. (Riparian forest)	Mountains of northern and south-western New Mexico, eastern Arizona, and southern Colorado (8,000-9,100)	Warm to cool moist	*P. pungens* climax or co-climax with *P. menziesii. A. lasiocarpa* minor climax	*P. menziesii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*P. pratensis* *E. eximius* (*E. superbus*) *G. richardsonii* *F. ovalis* (*F. virginiana*)	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Picea pungens/ Poa spp. H.T. (Not riparian)	Mountains of north-central Colorado (6,500-8,000)	Warm to well-drained	*P. pungens* climax	Usually pure stands. May contain *P. menziesii* *P. tremuloides*	*Poa* spp. *A. alnifolia* *Rosa* spp. *Salix* spp.	Hoffman and Alexander 1983
Picea pungens/ Carex foenea H.T. [*P. pungens/C. foenea* H.T. *Pseudotsuga menziesii* phase]	Mountains of northern and eastern Arizona, northern and southwestern New Mexico, and southern Colorado (8,000-9,500)	Cool moist to well-drained	*P. pungens* co-climax with *P. menziesii. A. concolor P. engelmannii* minor climaxes	*P. menziesii* *A. concolor* *P. engelmannii* *P. ponderosa* *P. strobiformis* *P. flexilis* *P. tremuloides*	*C. foenea* *B. repens* *F. arizonica* *M. montana* *B. ciliatus* *Festuca* spp. *F. ovalis* (*F. virginiana*)	Alexander et al. 1987 DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Picea pungens/ Arnica cordifolia H.T. (Riparian forest)	Front Range, north-central Colorado (7,500-9,000)	Cool moist	*P. pungens* climax	*P. menziesii* *A. lasiocarpa* *P. ponderosa* *P. contorta* *P. tremuloides*	*A. cordifolia* *J. communis* *R. woodsii* *C. canadensis* *S. stellata*	Hess and Alexander 1986
Picea pungens/ Equisetum arvense H.T.	Mountains of southern Utah (8,000-9,000)	Warm moist	*P. pungens* climax. *P. engelmannii* minor climax	*P. engelmannii* *P. menziesii* *P. tremuloides*	*E. arvense* *G. richardsonii* *O. chilensis* *T. fendleri*	Youngblood and Mauk 1985
Picea pungens/ Erigeron eximius H.T. [*P. pungens- Picea engelmannii/ E. superbus* H.T.] *E. eximius* (typic) phase *Pinus ponderosa* phase (AZ,NM)	Mountains of northern and southwestern New Mexico, eastern Arizona, and southern Colorado (8,000-9,800)	Cool moist to well-drained	*P. pungens* co-climax with *A. concolor P. menziesii P. engelmannii. A. lasiocarpa* minor climax	*A. concolor* *P. menziesii* *P. engelmannii* *A. lasiocarpa* *P. ponderosa* *P. strobiformis* *P. flexilis* *P. tremuloides*	*E. eximius* (*E. superbus*) *B. ciliatus* *C. foenea* *G. richardsonii* *F. vesca* (*F. americana*) *H. parryi* *T. fendleri*	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Picea pungens/ Fragaria ovalis H.T.	Mountains of southern New Mexico (7,500-9,800)	Cool moist	*P. pungens* co-climax with *P. menziesii. A. concolor P. engelmannii* minor climaxes	*P. menziesii* *A. concolor* *P. engelmannii* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*F. ovalis* (*F. virginiana*) *A. glabrum* *H. dumosus* *B. richardsonii* *P. pratensis* *F. vesca* (*F. americana*)	Alexander et al. 1984a
Picea pungens/ Senecio cardamine H.T. [*P. pungens- Picea engelmannii/ S. cardamine* H.T.]	Mountains of eastern Arizona and southwestern New Mexico (8,800-9,200)	Cool moist	*P. pungens* co-climax with *A. lasiocarpa P. engelmannii A. concolor*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. concolor* *P. ponderosa*	*S. caradmine* *F. ovalis* (*F. virginiana*) *G. richardsonii* *Helenium hoopesii*	Fitzhugh et al. 1987 Moir and Ludwig 1979

Juniperus communis phase *Valeriana acutiloba* phase	southern Colorado (7,800-9,500)		*P. engelmannii* minor climax in some phases	*P. strobiformis* *P. ponderosa* *P. tremuloides*	*E. eximius* (*E. superbus*) *L. arizonicus* *V. acutiloba*	
Abies grandis series						
Abies grandis/ Acer glabrum H.T. *A. glabrum* (typic) phase *Physocarpus malvaceus* phase	Mountains of central Idaho (3,800-6,400)	Cool moist	*A. grandis* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. ponderosa*	*A. glabrum* *P. malvaceus* *S. betulifolia* *S. albus* *C. rubescens*	Steele et al. 1981
Abies grandis/ Linnaea borealis H.T. *L. borealis* (typic) phase *Vaccinium globulare* phase (ID) *Xerophyllum tenax* phase	Mountains of northern (2,200-5,200) and central Idaho, and southern Montana (3,400-5,600)	Warm moist to well-drained	*A. grandis* climax. *A. lasiocarpa* minor climax in some phases	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. contorta* *P. ponderosa* *L. occidentalis*	*L. borealis* *A. alnifolia* *V. globulare* *C. rubescens* *A. cordifolia* *Lupinus* spp. *X. tenax*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981
Abies grandis/ Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington (2,600-4,900)	Cool dry to well-drained	*A. grandis* climax	*P. menziesii* *P. engelmannii* *P. contorta* *P. ponderosa* *Pinus monticola* *L. occidentalis*	*P. myrsinites* *L. borealis* *Bromus vulgaris* *G. triflorum* *S. stellata* *T. occidentale*	Daubenmire and Daubenmire 1968
Abies grandis/ Physocarpus malvaceus H.T. *P. malvaceus* (typic) phase *Coptis occidentalis* phase	Mountains of northern Idaho (2,200-5,300)	Warm dry	*A. grandis* climax	*P. menziesii* *P. contorta* *P. ponderosa* *P. monticola* *L. occidentalis*	*P. malvaceus* *A. glabrum* *H. discolor* *C. occidentalis* *O. chilensis* *S. racemosa*	Cooper et al. 1987
Abies grandis/ Spiraea betulifolia H.T.	Mountains of northern and central Idaho (4,300-6,400)	Warm dry	*A. grandis* climax	*P. menziesii* *P. ponderosa* *P. tremuloides*	*S. betulifolia* *S. albus* *C. rubescens* *A. cordifolia*	Cooper et al. 1987 Steele et al. 1981
Abies grandis/ Vaccinium caespitosum H.T.	Mountains of central Idaho (4,600-5,500)	Cool moist to well-drained frost pockets	*A. grandis* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. contorta* *P. ponderosa* *L. occidentalis*	*V. caespitosum* *C. rubescens* *C. geyeri* *F. ovalis* (*F. virginiana*) *T. occidentale*	Steele et al. 1981
Abies grandis/ Vaccinium globulare H.T.	Mountains of northern and central Idaho (4,500-6,500)	Cool moist	*A. grandis* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. ponderosa* *P. contorta* *L. occidentalis*	*V. globulare* *Lonicera utahensis* *S. betulifolia* *C. rubescens* *C. geyeri* *C. rossii*	Cooper et al. 1987 Steele et al. 1981
Abies grandis/ Calamagrostis rubescens H.T.	Mountains of central Idaho (5,200-6,100)	Cool dry	*A. grandis* climax	*P. menziesii* *P. contorta* *P. ponderosa* *L. occidentalis*	*C. rubescens* *S. betulifolia* *C. geyeri* *A. cordifolia*	Steele et al. 1981
Abies grandis/ Asarum caudatum H.T. *A. caudatum* (typic) phase *Menziesii ferruginea* phase *Taxis brevifolia* phase	Mountains of northern Idaho (2,200-5,950)	Warm moist	*A. grandis* climax. *A. lasiocarpa* may be minor climax	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *L. occidentalis*	*A. caudatum* *H. discolor* *M. ferruginea* *T. brevifolia* *C. uniflora* *C. occidentalis*	Cooper et al. 1987

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Abies grandis/ Clintonia uniflora H.T. *C. uniflora* (typic) phase *Menziesia ferruginea* phase (ID) *Physocarpus malvaceus* phase (ID) *Taxis brevifolia* phase (ID) *Aralia nudicaulis* phase (MT) *Xerophyllum tenax* phase	Mountains of northern Montana, and northern and central Idaho (2,000-6,100)	Warm moist	*A. grandis* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. contorta* *P. ponderosa* *P. monticola* *L. occidentalis*	*C. uniflora* *A. glabrum* *L. borealis* *M. ferruginea* *P. malvaceus* *T. brevifolia* *V. globulare* *B. vulgaris* *A. nudicaulis* *G. triflorum* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981
Abies grandis/ Coptis occidentalis H.T.	Mountains of central Idaho (1,600-6,000)	Warm dry	*A. grandis* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. ponderosa* *L. occidentalis*	*C. occidentalis* *S. albus* *V. globulare* *X. tenax*	Steele et al. 1981
Abies grandis/ Senecio triangularis H.T.	Mountains of northern Idaho (2,600-4,600)	Warm moist	*A. grandis* climax. *A. lasiocarpa* may be minor climax	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *L. occidentalis*	*S. triangularis* *Athyrium filix-femina* *Circaea alpina* *C. occidentalis* *Trautvettera carolinensis*	Cooper et al. 1987
Abies grandis/ Xerophyllum tenax H.T. *X. tenax* (typic) phase *Vaccinium globulare* phase (ID) *Coptis occidentalis* phase (ID)	Mountains of northern and central Idaho, and northwestern Montana (4,400-6,500)	Cool dry	*A. grandis* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. contorta* *P. ponderosa* *L. occidentalis*	*X. tenax* *P. myrsinites* *V. globulare* *Vaccinium scoparium* *C. rubescens* *Arnica latifolia* *C. occidentalis*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981
			Thuja plicata series			
Thuja plicata/ Oplopanax horridum H.T.	Mountains of Montana, northern Idaho, and eastern Washington (1,600-4,900)	Cool moist	*T. plicata* climax or co-climax with *T. heterophylla*. *A. lasiocarpa* may be minor climax	*T. heterophylla* *A. lasiocarpa* *P. menziesii* *P. engelmannii* *A. grandis* *P. monticola* *L. occidentalis*	*O. horridum* *A. filix-femina* *Dryopteris dilatata* *S. triangularis* *S. stellata* *Streptopus amplexifolius* *Tiarella* spp.	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977
Thuja plicata/ Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington (2,600-4,700)	Cool dry to well-drained	*T. plicata* climax	*P. engelmannii* *P. menziesii* *A. grandis* *P. monticola* *L. occidentalis*	*P. myrsinites* *A. glabrum* *C. occidentalis* *Disporum oregonum* *G. triflorum* *S. stellata*	Daubenmire and Daubenmire 1968
Thuja plicata/ Adiantum pedatum H.T.	Mountains of northern Idaho (≤3,000)	Cool moist	*T. plicata* climax. *T. heterophylla* minor climax	*T. heterophylla* *A. grandis* *P. monticola* *L. occidentalis*	*A. pedatum* *A. filix-femina* *C. uniflora* *D. dilatata*	Cooper et al. 1987
Thuja plicata/ Asarum caudatum H.T. *A. caudatum* (typic) phase *Menziesia ferruginea* phase *Taxis brevifolia* phase	Mountains of northern Idaho (2,200-5,200)	Warm moist	*T. plicata* climax	*A. lasiocarpa* *P. engelmanni* *A. grandis* *P. menziesii* *P. contorta* *P. monticola*	*A. caudatum* *A. glabrum* *M. ferruginea* *T. brevifolia* *C. occidentalis* *Polystichum munitum*	Cooper et al. 1987

Adiantum pedatum phase (ID)	Washington (1,500-4,700)		*T. heterophylla*	*A. grandis* *P. monticola*	*S. triangularis* *S. amplexifolius*	
Thuja plicata/ Clintonia uniflora H.T. *C. uniflora* (typic) phase *Menziesia ferruginea* phase *Taxis brevifolia* phase (ID) *Aralia nudicaulis* phase (MT) *Xerophyllum tenax* phase (ID)	Mountains of northern Idaho and northwestern Montana (1,500-5,500)	Warm dry bottomlands	*T. plicata* climax. *A. lasiocarpa* *A. grandis* *T. heterophylla* minor climaxes	*A. lasiocarpa* *A. grandis* *T. heterophylla* *P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis*	*C. uniflora* *L. borealis* *M. ferruginea* *V. globulare* *T. brevifolia* *A. nudicaulis* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977
Thuja plicata/ Gymnocarpium dryopteris H.T.	Mountains of northern Idaho (3,200-4,500)	Cool dry	*T. plicata* climax	*P. engelmannii* *P. menziesii* *A. grandis* *P. monticola*	*G. dryopteris* *A. pedatum* *A. filix-femina* *C. uniflora*	Cooper et al. 1987
			***Tsuga heterophylla* series**			
Tsuga heterophylla/ Menziesia ferruginea H.T.	Mountains of northern Idaho (±5,000)	Warm well-drained	*T. heterophylla* climax	*A. lasiocarpa* *P. engelmannii*	*M. ferruginea* *V. globulare* *X. tenax*	Cooper et al. 1987
Tsuga heterophylla/ Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington (2,700-3,900)	Cool moist	*T. heterophylla* climax	*T. plicata* *P. menziesii* *A. grandis* *P. monticola* *L. occidentalis*	*P. myrsinites* *L. borealis* *Vaccinium membranaceum* *C. uniflora* *G. dryopteris*	Daubenmire and Daubenmire 1968
Tsuga heterophylla/ Asarum caudatum H.T. *A. caudatum* (typic) phase *Menziesia ferruginea* phase *Aralia nudicaulis* phase	Mountains of northern Idaho (2,200-5,000)	Warm well-drained	*T. heterophylla* climax	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. grandis* *P. monticola* *P. contorta* *L. occidentalis* *T. plicata*	*A. caudatum* *L. borealis* *M. ferruginea* *P. myrsinites* *A. nudicaulis* *C. uniflora* *C. occidentalis* *P. hookeri*	Cooper et al. 1987
Tsuga heterophylla/ Clintonia uniflora H.T. *C. uniflora* (typic) phase *Menziesia ferruginea* phase (ID) *Aralia nudicaulis* phase *Xerophyllum tenax* phase (ID)	Mountains of northern Idaho and northwestern Montana (2,000-4,500)	Warm moist to well-drained	*T. heterophylla* climax. *A. lasiocarpa* *A. grandis* *T. plicata* minor climaxes	*A. lasiocarpa* *A. grandis* *T. plicata* *P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *L. occidentalis*	*C. uniflora* *M. ferruginea* *T. brevifolia* *V. globulare* *V. membraneceum* *A. nudicaulis* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977
Tsuga heterophylla/ Gymnocarpium dryopteris H.T.	Mountains of northern Idaho (2,500-4,500)	Warm dry to well-drained	*T. heterophylla* co-climax with *T. plicata*	*T. plicata* *P. engelmannii* *A. grandis* *P. monticola* *L. occidentalis*	*G. dryopteris* *A. caudatum* *C. uniflora* *C. occidentalis* *S. stellata*	Cooper et al. 1987
			***Pinus flexilis* series**			
Pinus flexilis/ Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado (9,500-10,000)	Cool dry	*P. flexilis* co-climax with *P. menziesii. P. engelmannii* minor climax	*P. menziesii* *P. engelmannii* *P. tremuloides*	*A. uva-ursi* *J. communis*	DeVelice et al. 1986
Pinus flexilis/ Berberis repens H.T.	Mountains of northern Utah (6,500-7,000)	Warm dry	*P. flexilis* climax	*P. menziesii* *J. scopulorum*	*B. repens* *P. myrsinites* *P. virginiana* *S. oreophilus* *A. spicatum*	Mauk and Henderson 1984

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pinus flexilis/ *Cercocarpus ledifolius* H.T.	Mountains of southeastern Idaho and northern Utah (7,000-8,700)	Warm dry	*P. flexilis* climax or co-climax with *P. menziesii*. *J. scopulorum* minor climax	*P. menziesii* *J. scopulorum*	*C. ledifolius* *B. repens* *S. oreophilus* *A. spicatum* *H. kingii* *B. sagittata*	Mauk and Henderson 1984 Steele et al. 1983
Pinus flexilis/ *Juniperus communis* H.T.	Mountains of Montana (4,600-8,300), northwestern Wyoming (7,000-9,500), southeastern Wyoming, and central and western Colorado (8,300-9,300)	Warm dry	*P. flexilis* climax. *P. menziesii* *P. contorta* *P. albicaulis* minor climaxes	*P. menziesii* *P. contorta* *P. albicaulis* *P. engelmannii* *P. ponderosa* *P. tremuloides*	*J. communis* *A. uva-ursi* *S. canadensis* *C. purpurascens* *C. rossii* *A. cordifolia*	Alexander et al. 1986 Hess and Alexander 1986 Hoffman 1988 Hoffman and Alexander 1980 Pfister et al. 1977 Steele et al. 1983
Pinus flexilis *Agropyron spicatum* H.T.	Mountains of Montana east of Continental Divide (4,400-6,600)	Warm very dry	*P. flexilis* climax or co-climax with *J. scopulorum*. *P. ponderosa* minor climax	*P. ponderosa* *J. scopulorum*	*A. spicatum* *B. gracilis* *H. kingii* *K. cristata* (*K. macrantha*) *Carex* spp.	Pfister et al. 1977
Pinus flexilis/ *Calamagrostis purpurascens* H.T.	Mountains of north-central Colorado (9,700-11,000)	Cool dry	*P. flexilis* climax	Usually pure stands. May contain *P. engelmannii* *P. contorta*	*C. purpurascens* *Arenaria fendleri* *Erigeron* spp. *Pulsatilla ludoviciana*	Hess and Alexander 1986
Pinus flexilis/ *Festuca idahoensis* H.T. *F. idahoensis* (typic) phase *Festuca scabrella* phase (MT)	Mountains of southwestern Montana, central Idaho, and northwestern Wyoming (4,800-8,300)	Warm dry	*P. flexilis* co-climax with *P. menziesii*. *J. scopulorum* minor climax	*P. menziesii* *J. scopulorum*	*F. idahoensis* *A. tridentata* *A. scipatum* *H. kingii* *F. scabrella* *B. sagittata*	Pfister et al. 1977 Steele et al. 1981, 1983
Pinus flexilis/ *Hesperochloa kingii* H.T.	Mountains of northwestern and southeastern Wyoming (7,200-9,300)	Warm dry	*P. flexilis* climax or co-climax with *P. menziesii*. *P. scopulorum* minor climax	Usually pure stands (SE WY). May contain (NW WY) *P. menziesii* *J. scopulorum*	*H. kingii* *A. spicatum* *K. cristata* *C. rossii* *A. miser* *B. sagittata*	Alexander et al. 1986 Steele et al. 1983
Pinus flexilis/ *Saxifraga bronchialis* H.T. [*P. flexilis*/ *Ciliaria austromontana* H.T.]	Mountains of south-central Colorado (8,500-9,500)	Cool dry	*P. flexilis* climax	*P. menziesii*	*S. bronchialis* (*C. austromontana*) *J. communis* *R. woodsii* *S. oreophilus* *F. thurberi*	Komarkova et al. 1988
Pinus flexilis/ *Trifolium dasyphyllum* H.T.	Mountains of north-central Colorado (11,000-11,500)	Cool dry to well-drained	*P. flexilis* climax	Usually pure stands. May contain *P. engelmannii* *A. lasiocarpa*	*T. dasyphyllum* *C. foenea* *A. fendleri* *Mertensia viridis* *Oreoxis aipina*	Hess and Alexander 1986

	(9,000-10,200)		*P. menziesii* *J. scopulorum* minor climaxes	*P. tremuloides*	*A. patula* *C. rossii* *A. miser*	
Populus tremuloides series and other P. tremuloides-dominated vegetation						
Populus tremuloides/ *Acer glabrum* C.T. (Riparian forest)	Mountains of south-central Colorado (9,000-9,200)	Warm wet	*P. tremuloides* climax or stable	*P. engelmannii* *Populus balsamifera*	*A. glabrum* *B. repens* *R. montigenum* *O. depauperata* *T. fendleri*	Powell 1987
Populus tremuloides- *Abies lasiocarpa*/ *Amelanchier alnifolia* C.T.	Mountains of eastern Idaho and Utah (5,800-7,800)	Cool dry	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*A. alnifolia* *P. virginiana* *S. oreophilus* *Aster engelmannii* *O. chilensis* *T. fendleri*	Mueggler 1987
Populus tremuloides- *Pseudotsuga menziesii*/ *Amelanchier alnifolia* C.T.	Mountains of northern Utah and southeastern Idaho (5,600-7,500)	Warm dry	*P. tremuloides* seral to *P. menziesii*	*P. menziesii*	*A. alnifolia* *B. repens* *P. virginiana* *S. betulifolia* *S. oreophilus* *Agropyron trachycaulum* *Elymus glaucus* *T. fendleri*	Mueggler 1987
Populus tremuloides/ *Amelanchier alnifolia* C.T. [*P. tremuloides*/*A. alnifolia*- *Prunus virginiana* H.T.(CO)] [*P. tremuloides*/*A. alnifolia*- *Symphoricarpos oreophilus*/ *Bromus carinatus* C.T.] [*P. tremuloides*/*A. alnifolia*- *S. oreophilus*/ *Calamagrostis rubescens* C.T.] [*P. tremuloides*/*A. alnifolia*- *S. oreophilus*/ *Thalictrum fendleri* C.T.] [*P. tremuloides*/*A. alnifolia*- *S. oreophilus*/tall forb C.T.] [*P. tremuloides*/*A. alnifolia*- *Pteridium aquilinum* C.T.] [*P. tremuloides*/*A. alnifolia*- *T. fendleri* C.T.] [*P. tremuloides*/*A. alnifolia*- tall forb C.T.]	Mountains of southeastern Idaho, Utah, Nevada, western Wyoming (5,500-8,800), and central and western Colorado (8,000-8,500)	Warm dry	*P. tremuloides* climax (CO). Stable or grazing disclimax (ID,NE, UT,WY)	Usually pure stands	*A. alnifolia* *A. glabrum* *A. grandidentatum* *P. myrsinites* *P. virginiana* *Q. gambelii* *S. betulifolia* *S. oreophilus* *C. rubescens* *B. carinatus* *C. geyeri* *A. engelmannii* *Geranium viscosissimum* *O. chilensis* *P. aquilinum* *T. fendleri*	Johnston and Hendzel 1985 Komarkova et al. 1988 Mueggler 1987
Populus tremuloides- *Abies concolor*/ *Arctostaphylos patula* C.T.	Mountains of eastern Nevada (8,300-9,500)	Warm dry	*P. tremuloides* seral to *A. concolor*	*A. concolor* *P. menziesii*	*A. patula* *B. repens* *P. fendleriana* *C. rossii* *Penstemon watsoni* *S. jamesiana*	Mueggler 1987
Populus tremuloides/ *Arctostaphylos uva-ursi* H.T.; C.T.	Mountains of south-central Colorado; Front Range, Colorado (9,500-10,500)	Cool dry	*P. tremuloides* climax or seral to *P. contorta* *P. flexilis*	Usually pure stands. May contain *P. contorta* *P. flexilis* *A. lasiocarpa* *P. engelmannii*	*A. uva-ursi* *J. communis* *S. oreophilus* *Bromus porteri* *C. foenea* *Carex geophila*	Komarkova et al. 1988 Powell 1987 Radloff 1983

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Populus tremuloides/ Artemisia tridentata C.T.	Mountains of southeastern Idaho, Utah, Nevada, and western Wyoming (6,900-9,400)	Warm dry	*P. tremuloides* stable or seral to unknown ultimate climax	Usually pure stands	*A. tridentata* *J. communis* *S. oreophilus* *B. ciliatus* *S. occidentalis* *Taraxicum officinale*	Mueggler 1987
Populus tremuloides/ Berberis repens H.T.	Mountains of southwestern North Dakota, and southeastern Montana (3,500-4,000)	Warm dry to well-drained	*P. tremuloides* climax	Usually pure stands. May contain *A. negundo* *F. pennsylvanica*	*B. repens* *A. glabrum* *P. virginiana* *S. albus* *P. pratensis* *G. boreale*	Hansen and Hoffman 1988
Populus tremuloides/ Betula occidentalis H.T.	Theodore Roosevelt National Park, North Dakota (2,400-2,800)	Warm well-drained	*P. tremuloides* climax	*J. scopulorum* *A. negundo* *Crataegus chrysocarpa* *F. pennsylvanica* *Ulmus americana*	*B. occidentalis* *P. virginiana* *Symphoricarpos* spp. *Toxicodendron rydbergii* *O. micrantha* *Apocynum androsaemifolium*	Hansen et al. 1984
Populus tremuloides-Corylus cornuta H.T.(SD,WY); C.T.(CO) *Aralia nudicaulis* phase (SD) *Pteridium aquilinum* phase (SD)	Black Hills and Bear Lodge Mountains, South Dakota and eastern Wyoming (3,900-6,300); Front Range, Colorado (≥8,000)	Warm moist to well-drained	*P. tremuloides* climax (SD,WY). Stable or seral (CO) to *P. menziesii* *P. pungens*	*P. menziesii* (CO) *P. pungens* (CO) *Betula papyrifera*	*C. cornuta* *S. arbus* *A. nudicaulis* *Aster ciliolatus* *G. triflorum* *O. chilensis* *P. aquilinum* *V. canadensis*	Hoffman and Alexander 1987 Powell 1987
Populus tremuloides-Abies lasiocarpa/ Juniperus communis C.T.	Mountains of northern Utah and eastern Nevada (8,000-10,000)	Cool dry	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*J. communis* *B. repens* *S. oreophilus* *Bromus* spp. *S. occidentalis* *A. millefolium* *F. vesca* (*F. americana*) *T. officinale*	Mueggler 1987
Populus tremuloides-Pseudotsuga menziesii/ Juniperus communis C.T.	Mountains of northern Utah, plateaus of southern Utah, and mountains of eastern Nevada (7,500-9,200)	Warm dry	*P. tremuloides* seral to *P. menziesii*	*P. menziesii*	*J. communis* *B. repens* *S. oreophilus* *A. trachycaulum* *S. occidentalis* *Antennaria microphylla* *A. miser* *T. fendleri*	Mueggler 1987
Populus tremuloides-Pinus contorta/ Juniperus communis C.T.	Mountains of northern Utah (≥8,000)	Cool dry	*P. tremuloides* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. contorta*	*J. communis* *B. repens* *S. oreophilus* *A. trachycaulum* *C. geyeri* *A. millefolium*	Mueggler 1987

[*P. tremuloides/J. communis-Carex geyeri* C.T.(UT)] [*P. tremuloides/J. communis-Astragalus miser* C.T.(UT)] [*P. tremuloides/J. communis-Lupinus argenteus* C.T.(UT,WY)]	and Utah (8,000-9,000); Front Range, central Colorado (9,000-9,500)		unknown ultimate climax. Probably *P. menziesii*	*A. lasiocarpa* (CO) *P. engelmannii* (CO) *P. pungens* (CO) *P. contorta* *P. flexilis*	*S. canadensis* *S. oreophilus* *S. hystrix* *Stipa* spp. *C. geyeri* *C. rossii* *A. miser* *L. argenteus*	Powell 1987 Radloff 1983
Populus tremuloides/Lonicera involucrata C.T.	Front Range, central Colorado (9,700-10,200)	Cool moist to well-drained	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. balsamifera*	*L. involucrata* *R. montigenum* *R. woodsii* *B. porteri* *C. foenea* *F. ovalis* (*F. virginiana*)	Powell 1987 Radloff 1983
Populus tremuloides/Physocarpus monogynus C.T.	Front Range, central Colorado (8,500-9,500)	Cool moist	*P. tremuloides* seral to *P. menziesii*	*P. menziesii* *P. engelmannii* *P. contorta*	*P. monogynus* *S. oreophilus* *B. ciliatus* *Oryzopsis asperifolia* *G. boreale*	Powell 1987
Populus tremuloides/Ribes montigenum C.T. (Riparian forest)	Mountains of south-central Colorado (9,760-10,600)	Cool moist	*P. tremuloides* seral to *P. engelmannii*	*P. engelmannii* *P. menziesii*	*R. montigenum* *Betula frontinalis* *B. repens* *R. woodsii* *P. aquilinum*	Powell 1987
Populus tremuloides/Rubus parviflorus H.T.(CO); C.T.(ID,UT,WY)	Mountains of southeastern Idaho, western Wyoming, Utah (8,000-9,300), and western Colorado (8,000-10,000)	Cool moist	*P. tremuloides* climax (CO). Stable or seral to unknown ultimate climax (ID,UT,WY). Probably *A. lasiocarpa* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. contorta* (ID,UT,WY)	*R. parviflorus* *A. glabrum* *P. myrsinites* *S. oreophilus* *V. myrtillus* *A. cordifolia* *G. viscossisimum* *O. chilensis*	Hoffman 1988 Mueggler 1987
Populus tremuloides/Salix scouleriana C.T.	Mountains of southeastern Idaho, northern Utah, and eastern Nevada (5,800-7,400)	Warm to well-drained	*P. tremuloides* stable. May be climax	Usually pure stands	*S. scouleriana* *A. alnifolia* *P. virginiana* *S. oreophilus* *B. carinatus* *E. glaucus* *O. chilensis* *T. fendleri*	Mueggler 1987
Populus tremuloides/Sambucus racemosa C.T.	Mountains of Utah (8,000-10,500)	Cool dry	*P. tremuloides* stable or seral to unknown ultimate climax. Probably *A. lasiocarpa*	Usually pure stands. May contain *A. lasiocarpa*	*S. racemosa* *Sambucus ceurla* *A. trachycaulum* *B. carinatus* *Mertensia arizonica* *O. occidentalis* *Rudbeckia occidentalis* *T. fendleri*	Mueggler 1987
Populus tremuloides-Abies lasiocarpa/Shepherdia canadensis C.T.	Mountains of western Wyoming, southeastern Idaho, and northern Utah (7,000-8,300)	Cool dry to well-drained	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. flexilis*	*S. canadensis* *B. repens* *R. woodsii* *E. glaucus* *A. cordifolia* *O. chilensis* *T. fendleri*	Mueggler 1987

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Populus tremuloides/ Shepherdia canadensis C.T.	Mountains of southeastern Idaho and western Wyoming (8,000-9,000); Front Range, central Colorado (9,000-10,000)	Cool dry to well-drained	*P. tremuloides* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii* *P. menziesii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *P. flexilis*	*S. canadensis* *B. repens* *J. communis* *R. woodsii* *B. ciliatus* *G. boreale* *G. viscosissimum* *L. argenteus* *O. chilensis*	Powell 1987 Mueggler 1987
Populus tremuloides-Abies lasiocarpa/ Symphoricarpos oreophilus C.T. [*P. tremuloides-A. lasiocarpa/ S. oreophilus-Bromus carinatus* C.T.] [*P. tremuloides-A. lasiocarpa/ S. oreophilus-Thalictrum fendleri* C.T.] [*P. tremuloides-A. lasiocarpa/ S. oreophilus*-tall forb C.T.]	Mountains of southeastern Idaho, northern Utah, and western Wyoming (7,000-9,000)	Warm dry to well-drained	*P. tremuloides* seral to unknown ultimate climax. Probably *A. lasiocarpa*	May be pure stands. Usually contain *A. lasiocarpa* *A. concolor* *P. menziesii*	*S. oreophilus* *A. alnifolia* *A. tridentata* *B. repens* *P. virginiana* *B. carinatus* *C. rubescens* *E. glaucus* *P. pratensis* *C. geyeri* *G. viscosissimum* *L. argenteus* *R. occidentalis* *Senecio serra* *T. fendleri*	Mueggler 1987 Steele et al. 1983
Populus tremuloides-Abies concolor/ Symphoricarpos oreophilus C.T.	Mountains of northern Utah and eastern Nevada (7,000-9,000)	Warm dry	*P. tremuloides* seral to *A. concolor*	*A. concolor* *P. pungens*	*S. oreophilus* *B. repens* *R. woodsii* *A. trachycaulum* *E. glaucus* *A. engelmannii* *R. occidentalis* *O. chilensis* *S. serra*	Mueggler 1987
Populus tremuloides-Pseudotsuga menziesii/ Symphoricarpos oreophilus C.T.	Mountains of southeastern Idaho and northern Utah (6,000-7,500)	Warm dry	*P. tremuloides* seral to *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. contorta*	*S. oreophilus* *R. woodsii* *C. rubescens* *E. glaucus* *G. viscosissimum* *L. argenteus* *T. fendleri*	Mueggler 1987
Populus tremuloides-Pinus contorta/ Symphoricarpos oreophilus C.T.	Mountains of southeastern Idaho and northern Idaho (5,700-9,800)	Warm dry	*P. tremuloides* seral to unknown ultimate climax	*P. contorta*	*S. oreophilus* *P. myrsinites* *C. rubescens* *C. geyeri* *G. viscosissimum* *O. chilensis* *T. fendleri*	Mueggler 1987
Populus tremuloides/ Symphoricarpos oreophilus H.T., C.T.(CO);C.T.(ID,UT,NE,WY)	Mountains of Utah, south-eastern Idaho,	Warm moist to well-drained	*P. tremuloides* climax (CO). Stable or seral	Usually pure stands. Seral stands in CO may contain	*S. oreophilus* *B. repens* *P. myrsinites*	Hess and Wasser 1982 Hoffman 1988 Hoffman and

Calamagrostis rubescens C.T.] [*P. tremuloides/S. oreophilus-* *Festuca thurberi* C.T.(UT)] [*P. tremuloides/S. oreophilus-* *Poa pratensis* C.T.(NE,UT)] [*P. tremuloides/S. oreophilus-* *Carex geyeri* H.T.(CO)] [*P. tremuloides/S. oreophilus-* *Carex rossii* C.T.] [*P. tremuloides/S. oreophilus-* *Thalictrum fendleri* C.T.] [*P. tremuloides/S. oreophilus-* tall forb C.T.]	western Colorado (8,000-10,000)		*P. menziesii*		*P. pratensis* *C. geyeri* *C. rossii* *A. engelmannii* *M. arizonica* *R. occidentalis* *S. serra* *T. fendleri*	1988 Mauk and Henderson 1984 Mueggler 1987 Powell 1987
Populus tremuloides/ *Vaccinium caespitosum* C.T.	Front Range, central Colorado (7,600-7,800)	Cool moist to well-drained	*P. tremuloides* seral to *P. menziesii*	*P. menziesii*	*V. caespitosum* *A. glabrum* *A. alnifolia* *R. woodsii* *E. glaucus* *A. cordifolia*	Powell 1987
Populus tremuloides/ *Vaccinium myrtillus* C.T.	Front Range, central Colorado (9,000-10,500)	Cool dry	*P. tremuloides* seral to *A. lasiocarpa* *A. concolor* *P. engelmannii*	*A. lasiocarpa* *A. concolor* *P. engelmannii*	*V. myrtillus* *B. repens* *P. monogynus* *V. scoparium* *A. cordifolia*	Powell 1987
Populus tremulodies/ *Wyethia amplexicaulis* C.T.	Mountains of southeastern Idaho, Utah, eastern Nevada, and western Wyoming (≤7,000)	Cool well-drained	*P. tremuloides* stable or seral to unknown ultimate climax	Usually pure stands	*W. amplexicaulis* *B. carinatus* *P. pratensis* *G. viscosissimum* *R. occidentalis* *S. serra*	Mueggler 1987
Populus tremuloides/ *Bromus carinatus* C.T.	Mountains of southeastern Idaho, Utah, eastern Nevada, and western Wyoming (6,200-10,000)	Warm to cool dry	*P. tremuloides* stable or seral to unknown ultimate climax. May be grazing disclimax	Usually pure stands	*B. carinatus* *A. trachycaulum* *E. glaucus* *P. pratensis* *A. millefolium* *R. occidentalis* *T. fendleri* *V. americana*	Mueggler 1987
Populus tremuloides/ *Bromus ciliatus* C.T.	Front Range, central Colorado (9,000-10,200)	Cool moist	*P. tremulodies* seral to *A. concolor* *A. lasiocarpa* *P. engelmannii*	*A. concolor* *A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. pungens* *P. contorta*	*B. ciliatus* *A. uva-ursi* *J. communis* *F. thurberi* *Poa* spp. *G. boreale* *S. stellata*	Powell 1987
Populus tremuloides/ *Calamagrostis canadensis* C.T.	Front Range, central Colorado (9,000-10,500)	Cool moist	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. menziesii* *P. contorta*	*C. canadensis* *R. woodsii* *P. pratensis* *Ligusticum porteri* *S. triangularis* *V. canadensis*	Powell 1987 Radloff 1983
Populus tremuloides- *Pseudotsuga menziesii/* *Calamagrostis rubescens* C.T.	Mountains of southeastern Idaho and western Wyoming (6,400-7,800)	Cool dry	*P. tremuloides* seral to *P. menziesii*	*P. menziesii* *P. contorta*	*C. rubescens* *S. oreophilus* *E. glaucus* *C. geyeri* *A. cordifolia* *L. argenteus* *O. chilensis*	Mueggler 1987

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Populus tremuloides/ *Calamagrostis rubescens* H.T. (SE WY);C.T.(NW WY,ID,UT)	Mountains of southeastern Idaho, Utah, and northwestern and southeastern Wyoming (8,000-8,600)	Cool dry	*P. tremuloides* climax (SE WY). Stable or seral to unknown ultimate climax (NW WY,ID,UT). Probably *A. lasiocarpa* *P. menziesii*	Usually pure stands (SE WY). May contain *A. lasiocarpa* *P. menziesii* *P. contorta* (NW WY,ID,UT)	*C. rubescens* *S. oreophilus* *P. pratensis* *C. geyeri* *Fragaria* spp. *G. viscosissimum* *O. chilensis* *T. fendleri*	Alexander et al. 1986 Mueggler 1987
Populus tremuloides/ *Elymus glaucus* C.T.	Front Range, central Colorado (9,500-10,000)	Cool wet	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*E. glaucus* *B. ciliatus* *P. pratensis* *Aconitum columbianum* *Erigeron* spp. *Heracleum sphondyllum* (*H. lanatum*)	Powell 1987
Populus tremuloides/ *Festuca arizonica* H.T.	Mountains of south-central Colorado (9,500-10,000)	Warm dry	*P. tremuloides* climax	Usually pure stands	*F. arizonica* *F. thurberi* *M. montana* *L. argenteus*	Komarkova et al. 1988
Populus tremuloides/ *Festuca thurberi* H.T.,C.T.(CO); C.T.(UT) [*P. tremuloides*/*F. thurberi*-*Carex geyeri* H.T.(CO)]	Mountains of Utah (8,000-10,000) and Colorado (9,000-10,500)	Warm dry	*P. tremuloides* climax or stable (CO). Stable or seral to unknown ultimate climax (UT). Probably *A. lasiocarpa* *P. engelmannii*	Usually pure stands. May contain *A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *P. flexilis*	*F. thurberi* *S. oreophilus* *B. carinatus* *S. occidentalis* *C. geyeri* *L. leucanthus* *T. officinale* *T. fendleri*	Hess and Alexander 1986 Hess and Wasser 1982 Johnston and Hendzel 1985 Komarkova et al. 1988 Mueggler 1987 Powell 1987
Populus tremuloides-*Abies concolor*/ *Poa pratensis* C.T.	Mountains of southern Utah and eastern Nevada (8,000-8,800)	Warm dry to well-drained	*P. tremuloides* seral to *A. concolor*	*A. concolor* *P. menziesii*	*P. pratensis* *J. communis* *A. trachycaulum* *B. carinatus* *S. occidentalis* *T. officinale* *T. fendleri*	Mueggler 1987
Populus tremuloides/ *Poa pratensis* C.T.	Mountains of southeastern Idaho, southern Utah, and eastern Nevada (7,000-9,000); Front Range, central Colorado (8,500-9,600)	Cool moist to well-drained	*P. tremuloides* stable or seral to unknown ultimate climax (ID,NE,UT). May be grazing disclimax. Seral (CO) to *A. lasiocarpa* *A. concolor* *P. pungens* *P. menziesii*	*A. lasiocarpa* *A. concolor* *P. pungens* *P. menziesii* *P. engelmannii* *P. ponderosa* *P. flexilis*	*P. pratensis* *P. monogynus* *B. carinatus* *C. rubescens* *P. nervosa* *A. millefolium* *S. stellata* *T. officinale* *T. fendleri* *Trifolium longipes* *V. americana*	Mueggler 1987 Powell 1987
Populus tremuloides/ *Stipa comata* C.T.	Mountains of southeastern Idaho south to the	Warm dry	*P. tremuloides* stable or seral to unknown	Usually pure stands. May contain *P. ponderosa*	*S. comata* *F. idahoensis* *P. fendleriana*	Mueggler 1987

			P. menziesii (low elevations) *A. lasiocarpa* *P. engelmannii* (high elevations)	*P. engelmannii* *P. contorta* *P. flexilis*	*A. millefolium* *A. miser* *F. ovalis* (*F. virginiana*) *Thermopsis divaricarpa*	
Populus tremuloides-Abies lasiocarpa/Carex geyeri C.T.	Mountains of southeastern Idaho, Utah, and western Wyoming (6,000-10,000)	Cool dry	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*C. geyeri* *S. oreophilus* *C. rubescens* *S. occidentalis* *C. rossii* *A. millefolium* *A. miser* *F. vesca* (*F. americana*) *O. chilensis* *T. fendleri* *T. longipes*	Mueggler 1987
Populus tremuloides-Pinus contorta/Carex geyeri C.T.	Mountains of southeastern Idaho and northeastern Utah (6,200-9,400)	Cool dry	*P. tremuloides* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*C. geyeri* *V. scoparium* *C. rubescens* *L. argenteus* *O. chilensis* *T. fendleri*	Mueggler 1987
Populus tremuloides/Carex geyeri H.T.	Mountains of Utah, southeastern Wyoming, and north-central and west-central Colorado (7,500-10,000)	Cool dry to well-drained	*P. tremuloides* climax (CO,WY). Seral to unknown ultimate climax (UT)	Usually pure stands. May contain (CO) *A. lasiocarpa* *P. contorta* *P. flexilis*	*G. geyeri* *B. repens* *J. communis* *S. oreophilus* *C. rossii* *C. rubescens* *A. cordifolia* *L. leucanthus* *Ligusticum* spp. *O. depauperata*	Alexander et al. 1986 Hess and Alexander 1986 Hoffman and Alexander 1983 Johnston and Hendzel 1985 Mauk and Henderson 1984
Populus tremuloides-Abies lasiocarpa/Carex rossii C.T.	Mountains of southern Utah and eastern Nevada (8,000-10,300)	Cool dry	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*C. rossii* *Bromus anomalus* *A. miser* *L. argenteus* *T. officinale* *Trifolium* spp.	Mueggler 1987
Populus tremuloides/Carex rossii C.T.	Mountains of southern Utah and eastern Nevada (8,000-10,500)	Cool dry	*P. tremuloides* stable or seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. flexilis*	*C. rossii* *A. tridentata* *S. oreophilus* *A. trachycaulum* *B. anomalus* *P. fendleriana* *S. occidentalis* *T. officinale*	Mueggler 1987
Populus tremuloides/Astragalus miser C.T.	Mountains of western Wyoming and Utah (7,500-10,000), and south-central Colorado (10,000-10,600)	Cool to well-drained	*P. tremuloides* stable or seral to unknown ultimate climax. May be grazing disclimax (UT).	*P. flexilis*	*A. miser* *C. geyeri* *A. millefolium* *G. viscosissimum* *L. argenteus* *T. fendleri*	Mueggler 1987 Powell 1987

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Populus tremuloides/ Heracleum sphondyllium H.T., C.T. [*P. tremuloides/ Heracleum lanatum* H.T.]	Mountains of south-central and western Colorado (8,500-9,900)	Warm moist to wet	*P. tremuloides* climax or stable	Usually pure stands. May contain *P. balsamifera*	*H. sphondyllium (H. lanatum)* *A. tenuifolia* *B. ciliatus* *E. glaucus* *Pedicularis bracteosa* *T. fendleri*	Hess and Wasser 1982 Hoffman 1988 Hoffman and Alexander 1980, 1983 Powell 1987
Populus tremuloides/ Lathyrus leucanthus C.T.	Front Range, central Colorado (10,000-10,500)	Cool moist to well-drained	*P. tremuloides* stable or seral to unknown ultimate climax. May be grazing disclimax.	Usually pure stands	*L. leucanthus* *R. woodsii* *B. porteri* *F. thurberi* *A. millefolium*	Powell 1987
Populus tremuloides/ Ligularia bigelovii C.T. [*P. tremuloides Senecio bigelovii* C.T.]	Front Range, central Colorado (8,500-9,000)	Cool moist	*P. tremuloides* seral to unknown ultimate climax. Probably *P. menziesii* *P. pungens* *A. concolor*	*P. menziesii* *P. pungens* *A. concolor* *P. contorta*	*L. bigelovii* *J. communis* *R. woodsii* *F. ovalis (F. virginiana)* *G. boreale* *G. richardsonii*	Powell 1987
Populus tremuloides/ Ligusticum porteri H.T.;C.T.	Front Range, central Colorado, and mountains of southwestern Colorado (9,000-10,000)	Warm moist to well-drained	*P. tremuloides* climax or seral to unknown ultimate climax. Probably *A. concolor* *P. pungens* *P. menziesii*	Usually pure stands. May contain *A. concolor* *P. pungens* *P. menziesii* *P. flexilis*	*L. porteri* *S. oreophilus* *C. geyeri* *L. leucanthus* *T. fendleri* *V. americana*	Johnston and Hendzel 1985 Powell 1987
Populus tremuloides/ Lupinus argenteus H.T.	Bighorn Mountains, north-central Wyoming (7,000-7,800)	Warm well-drained	*P. tremuloides* climax	Usually pure stands	*Lupinus* spp. *Carex* spp. *Trifolium* spp.	Hoffman and Alexander 1976
Populus tremuloides/ Pteridium aquilinum H.T.,C.T. (CO);C.T.(UT)	Front Range, central Colorado; mountains of western and south-central Colorado (8,000-9,000), and northern Utah (5,800-9,400)	Warm poorly-drained	*P. tremuloides* climax or stable (CO). Stable or seral to unknown ultimate climax (UT)	Usually pure stands. May contain *P. menziesii* (FR CO)	*P. aquilinum* *B. carinatus* *E. glaucus* *C. geyeri* *Melica subulata* *R. occidentalis* *S. serra* *T. fendleri*	Hoffman 1988 Hoffman and Alexander 1980, 1983 Komarkova et al. 1988 Mueggler 1987 Powell 1987
Populus tremuloides- Abies lasiocarpa/ Thalictrum fendleri C.T.	Mountains of southeastern Idaho, western Wyoming, Utah, and eastern Nevada (7,000-10,100)	Cool moist	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*T. fendleri* *P. myrsinites* *S. oreophilus* *B. carinatus* *C. rossii* *G. viscosissimum* *O. chilensis*	Mueggler 1987
Populus tremuloides- Pinus contorta/ Thalictrum fendleri C.T.	Mountains of northern Utah (7,100-8,900)	Warm moist to well-drained	*P. tremuloides* seral to unknown ultimate climax.	*A. lasiocarpa* *P. contorta*	*T. fendleri* *S. oreophilus* *A. trachycaulum*	Mueggler 1987

NE,UT) [*P. tremuloides/T. fendleri-* *Carex geyeri* H.T.(CO)] *T. fendleri* (typic) phase *Delphinium barbeyi* phase (CO) *Ligusticum porteri* phase (CO)	eastern Nevada, western and southeastern Wyoming, and Colorado (8,000-10,500)		seral to unknown ultimate climax (FR CO, ID, NE, *UT*). Probably *A. lasiocarpa* *P. menziesii*	*P. menziesii* *P. flexilis* *P. contorta*	*C. geyeri* *D. barbeyi* *G. richardsonii* *L. leucanthus* *Ligusticum filicinum* *L. porteri* *L. argenteus*	Hess and Wasser 1982 Hoffman 1988 Hoffman and Alexander 1980, 1983 Komarkova et al. 1988 Johnston and Hendzel 1985 Mueggler 1987 Powell 1987
Populus tremuloides/ *Thermopsis divaricarpa* C.T.	Front Range, central Colorado (9,600-10,400)	Cool moist	*P. tremuloides* seral to *A. concolor* *P. menziesii* (low elevations) *A. lasiocarpa* *P. engelmannii* (high elevations)	*A. concolor* *P. menziesii* *A. lasiocarpa* *P. engelmannii* *P. contorta*	*T. divaricarpa* *J. communis* *R. woodsii* *C. foenea* *A. millefolium* *F. ovalis* (*F. virginiana*)	Powell 1987
Populus tremuloides/ *Veratrum tenuipetalum* H.T.(CO) [*P. tremuloides/* *V. californicum* C.T.(NE,UT)]	Mountains of northwestern Colorado, northern Utah, and eastern Nevada (7,000-8,000)	Cool moist	*P. tremuloides* climax (CO). Stable or seral to unknown ultimate climax (NE,UT)	Usually pure stands	*V. californicum* *V. tenuipetalum* *B. ciliatus* *Poa alpinum* *Carex hoodii* *L. porteri* *M. arizonica* *Mertensia ciliata* *S. jamesiana*	Hoffman and Alexander 1980 Mueggler 1987
Populus tremuloides- *Abies lasiocarpa/* Tall forb C.T.	Mountains of southeastern Idaho, western Wyoming, Utah, and eastern Nevada (6,600-10,200)	Warm well- drained	*P. tremuloides* seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*B. carinatus* *E. glaucus* *A. engelmannii* *Delphinium occidentalis* *Osmorhiza* spp. *R. occidentalis* *Valeriana occidentalis*	Mueggler 1987
Populus tremuloides/ Tall forb C.T.	Mountains of western Wyoming, Utah, and eastern Nevada (7,000-9,000)	Warm moist to well- drained	*P. tremuloides* stable or seral to *A. lasiocarpa*	*A. lasiocarpa*	*Agastache urticifolia* *A. engelmannii* *D. occidentalis* *Hackelia floribunda* *H. sphondyllium* (*H. lanatum*) *M. arizonica*	Mueggler 1987
Populus tremuloides- *Pinus ponderosa* C.T.	Mountains of Utah (8,000-8,900)	Warm dry	*P. tremuloides* seral to *P. ponderosa*	*P. ponderosa*	*B. repens* *J. communis* *Q. gambelii* *S. oreophilus* *P. fendleriana* *A. millefolium* *T. officinale*	Mueggler 1987
Populus tremuloides- *Pinus flexilis* C.T.	Mountains of western Wyoming, Utah, and eastern Nevada ($\geq$9,000)	Cool dry	*P. tremuloides* usually stable. May be succeeded by *P. flexilis*	*P. flexilis*	*B. repens* *S. oreophilus* *A. trachycaulum* *C. rossii* *A. millefolium* *S. jamesiana*	Mueggler 1987

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Populus tremuloides- *Picea pungens* C.T.	Mountains of Utah (7,400-9,100)	Cool dry	*P. tremuloides* seral to *P. pungens*	*P. pungens*	*J. communis* *S. oreophilus* *B. anomalus* *P. pratensis* *A. millefolium* *T. officinale*	Mueggler 1987
			***Pinus contorta* series and other *P. contorta*-dominated vegetation**			
Pinus contorta/ *Arctostaphylos uva-ursi* H.T.	Mountains of northern Utah and north-central Wyoming; Front Range, Colorado (7,800-9,500)	Warm dry to well-drained	*P. contorta* climax or stable	Usually pure stands. May contain *P. tremuloides*	*A. uva-ursi* *B. repens* *J. communis* *S. betulifolia* *S. hystrix* *C. rossii*	Hoffman and Alexander 1976 Mauk and Henderson 1984 Radloff 1983
Pinus contorta/ *Berberis repens* C.T.	Mountains of northern Utah (7,700-10,000)	Cool dry to well-drained	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *A. concolor*	Usually *P. tremuloides.* May also contain *A. lasiocarpa* *A. concolor*	*B. repens* *A. patula* *J. communis* *P. myrsinites* *C. geyeri* *A. cordifolia* *L. argenteus*	Mauk and Henderson 1984
Pinus contorta/ *Juniperus communis* H.T.(CO, SE WY);C.T.(ID,NW WY, UT)	Mountains of southeastern Idaho, northwestern and southeastern Wyoming, northern Utah, and central and north-central Colorado (8,000-10,500)	Cool dry	*P. contorta* climax (CO,SE WY) or seral to unknown ultimate climax (ID,NW WY). Probably *A. lasiocarpa* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. ponderosa* *P. albicaulis* *P. tremuloides*	*J. communis* *A. uva-ursi* *B. repens* *S. canadensis* *A. cordifolia* *Lupinus* spp.	Alexander et al. 1986 Hess and Alexander 1986 Komarkova et al. 1988 Mauk and Henderson 1984 Radloff 1983 Steele et al. 1983
Pinus contorta/ *Linnaea borealis* C.T.	Mountains of Montana east of Continental Divide, and northwestern Wyoming (5,600-7,200)	Cool moist to well-drained	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. engelmannii*	*L. borealis* *V. globulare* *V. scoparium* *C. rubescens* *A. cordifolia* *A. latifolia*	Pfister et al. 1977 Steele et al. 1983
Pinus contorta/ *Purshia tridentata* H.T.	Mountains of western Montana (≤6,600)	Warm dry to well-drained	*P. contorta* climax or stable	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. tremuloides*	*P. tridentata* *A. uva-ursi* *A. spicatum* *F. idahoensis* *C. rossii* *Epilobium angustifolium*	Pfister et al. 1977
Pinus contorta/ *Shepherdia canadensis* H.T. (CO,SE WY);C.T.(ID,NW WY)	Mountains of southeastern Idaho (7,000-8,000), northwestern and southeastern Wyoming, and north-central Colorado	Warm dry to well-drained	*P. contorta* climax (CO,SE WY) or seral to unknown ultimate climax (ID,NW WY). Probably *A. lasiocarpa*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. tremuloides*	*S. canadensis* *A. uva-ursi* *J. communis* *L. borealis* *P. myrsinites* *R. woodsii*	Alexander et al. 1986 Hess and Alexander 1986 Hess and Wasser 1982

	(7,000-8,000)		*A. lasiocarpa*		*C. geyeri*	
Pinus contorta/ Vaccinium caespitosum C.T.	Mountains of south-central Montana, Idaho (5,000-7,500), and northern Utah (8,300-10,000)	Cool moist to well-drained	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. engelmannii*	*V. caespitosum* *J. communis* *L. borealis* *V. scoparium* *C. rubescens* *Festuca ovina*	Cooper et al. 1987; Mauk and Henderson 1984; Pfister et al. 1977; Steele et al. 1981
Pinus contorta/ Vaccinium globulare C.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah (7,500-9,000)	Cool well-drained	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. engelmannii*	*V. globulare* *L. utahensis* *V. scoparium* *C. rubescens*	Steele et al. 1983
Pinus contorta/ Vaccinium myrtillus H.T.	Front Range, Colorado (8,500-10,000)	Cool dry	*P. contorta* climax	*P. tremuloides*	*V. myrtillus* *L. borealis* *P. myrsinites* *C. geyeri*	Radloff 1983
Pinus contorta/ Vaccinium scoparium H.T. (CO,SE WY);C.T.(ID,UT,NW WY)	Mountains of Montana, Idaho, northwestern Wyoming (7,000-8,500), northern Utah, southeastern Wyoming, and western and central Colorado (8,500-10,500)	Cool dry	*P. contorta* climax (CO,SE WY) or seral to unknown ultimate climax (ID,NW WY, UT). Probably *A. lasiocarpa* *A. grandis* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *A. grandis* *P. engelmannii* *P. flexilis* *P. albicaulis* *L. occidentalis* *T. heterophylla*	*V. scoparium* *A. uva-ursi* *B. repens* *L. borealis* *J. communis* *C. rubescens* *C. geyeri* *C. rossii* *A. cordifolia* *L. argenteus*	Alexander et al. 1986; Cooper et al. 1987; Hess and Alexander 1986; Hoffman and Alexander 1980; Komarkova et al. 1988; Mauk and Henderson 1984; Pfister et al. 1977; Steele et al. 1981, 1983
Pinus contorta/ Calamagrostis canadensis C.T.	Mountains of northern Utah (8,800-9,800)	Cool moist	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*C. canadensis* *J. communis* *P. nervosa* *A. cordifolia*	Mauk and Henderson 1984
Pinus contorta/ Calamagrostis rubescens C.T.	Mountains of Montana, Idaho, northeastern Utah, and northwestern Wyoming (6,000-8,000)	Cool dry	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. engelmannii* *L. occidentalis*	*C. rubescens* *A. uva-ursi* *S. albus* *V. scoparium* *C. geyeri* *A. cordifolia*	Pfister et al. 1977; Steele et al. 1983
Pinus contorta/ Festuca idahoensis H.T.	Mountains of central Idaho (5,000-9,000)	Warm dry to well-drained	*P. contorta* climax. *P. albicaulis* minor climax	*P. albicaulis* *P. menziesii*	*F. idahoensis* *C. rossii* *Artemisia* spp. *Penstemon* spp.	Steele et al. 1981
Pinus contorta/ Carex geyeri H.T.(CO,SE WY); C.T.(ID,NW WY)	Mountains of central Idaho, northwestern Wyoming (6,000-9,000), southeastern Wyoming, and north-central Colorado (7,500-10,000)	Cool dry	*P. contorta* climax (CO) or seral to unknown ultimate climax (ID,WY). Probably *A. lasiocarpa* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. albicaulis* *P. flexilis* *P. tremuloides*	*C. geyeri* *B. repens* *J. communis* *P. myrsinites* *R. woodsii* *S. oreophilus* *A. cordifolia* *Fragaria* spp. *L. argenteus*	Alexander et al. 1986; Hess and Alexander 1986; Hess and Wasser 1982; Komarkova et al. 1988; Steele et al. 1981, 1983

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Pinus contorta/ Carex rossii H.T.(UT,SE WY); C.T.(NW WY)	Mountains of northern Utah, and northwestern and southeastern Wyoming (8,500-10,000)	Cool dry	*P. contorta* climax (SE WY,UT) or seral to unknown ultimate climax (NW WY). Probably *A. lasiocarpa* *P. engelmannii*	May be pure stands. Usually contain *A. lasiocrpa* *P. engelmannii* *P. albicaulis* *P. tremuloides*	*C. rossii* *P. nervosa* *L. argenteus* *Pyrola* spp. *Sedum lanceolatum* *Salidago multiradiata*	Alexander et al. 1986 Mauk and Henderson 1984 Steele et al. 1983
Pinus contorta/ Arnica cordifolia C.T.	Mountains of southeastern Idaho and northwestern Wyoming (6,000-9,000)	Cool dry	*P. contorta* seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii* *P. menziesii*	Usually pure stands. May contain *A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. albicaulis* *P. flexilis*	*A. cordifolia* *A. racemosa* *A. miser* *P. secunda*	Steele et al. 1983
Pinus contorta/ Xerophyllum tenax C.T.	Mountains of northern Idaho (6,000-8,000)	Cool dry	*P. contorta* seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*X. tenax* *V. globulare* *V. scoparium*	Cooper et al. 1987
			***Pinus aristata* series**			
Pinus aristata/ Juniperus communis H.T.	Mountains of south-central Colorado (9,500-10,000)	Cool dry	*P. aristata* climax or co-climax with *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides*	*J. communis* *A. uva-ursi* *Artemisia* spp. *M. montana* *P. fendleriana*	Komarkova et al. 1988
Pinus aristata/ Ribes montigenum H.T. (Scree forest)	Mountains of northern New Mexico and southern Colorado (11,000-11,500)	Cool dry	*P. aristata* climax	Usually pure stands. May contain *P. engelmannii*	*R. montigenum* *S. bronchialis*	DeVelice et al. 1986
Pinus aristata/ Festuca arizonica H.T.	Mountains of northern New Mexico, and southern and western Colorado (8,600-10,000)	Warm dry	*P. aristata* climax or co-climax with *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides*	*F. arizonica* *R. cereum* *K. cristata* *(K. macrantha)* *M. montana* *A. frigida*	DeVelice et al. 1986 Komarkova et al. 1988
Pinus aristata/ Festuca thurberi H.T.	Mountains of northern New Mexico and southern and western Colorado (10,000-11,800)	Cool dry	*P. aristata* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides*	*F. thurberi* *R. montigenum* *A. cordifolia* *Polemonium pulcherrimum* *(P. delicatum)* *S. bronchialis*	DeVelice et al. 1986 Komarkova et al. 1988
Pinus aristata/ Trifolium dasyphyllum H.T.	Mountains of north-central Colorado (11,400-11,600)	Cool dry	*P. aristata* climax. *P. engelmannii* minor climax	*P. engelmannii*	*T. dasyphyllum* *C. foenea* *A. lanulosa* *Penstemon whippleanus* *P. pulcherrimum* *(P. delicatum)*	Hess and Alexander 1986

***Picea glauca* series**

Vaccinium scoparium H.T.	and Bear Lodge Mountains, South Dakota and eastern Wyoming (5,700-6,700)	drained	climax	*P. tremuloides* *B. papyrifera*	*B. repens* *J. communis* *S. betulifolia* *F. ovalis* (*F. virginiana*) *G. boreale*	Alexander 1987
			***Picea engelmannii* series**			
Picea engelmannii/ *Acer glabrum* H.T.	Mountains of south-central Arizona and southern New Mexico (8,500-9,500)	Cool moist	*P. engelmannii* climax. *A. lasiocarpa* *P. engelmannii* minor climaxes	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. concolor* *P. strobiformis* *P. tremuloides*	*A. glabrum* *B. ciliatus* *L. porteri* *S. stellata* *V. canadensis*	Alexander et al. 1984a DeVelice and Ludwig 1983 Moir and Ludwig 1979
Picea engelmannii/ *Juniperus communis* H.T.	Mountains of northwestern Wyoming (7,400-10,300)	Cool dry	*P. engelmannii* climax	*P. menziesii* *P. contorta* *P. flexilis* *P. albicaulis*	*J. communis* *A. cordifolia* *Frasera speciosa* *S. multiradiata*	Steele et al. 1983
Picea engelmannii/ *Linnaea borealis* H.T.	Mountains of Montana east of Continental Divide (4,200-7,800), and northwestern Wyoming (6,200-8,200)	Cool well-drained	*P. engelmannii* climax	*P. menziesii* *P. contorta*	*L. borealis* *J. communis* *S. albus* *V. globulare* *C. rubescens* *A. cordifolia* *P. secunda*	Pfister et al. 1977 Steele et al. 1983
Picea engelmannii/ *Physocarpus malvaceus* H.T.	Mountains of south-central Montana, southeastern Idaho, and northwestern Wyoming (5,900-7,200)	Cool moist	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. contorta*	*P. malvaceus* *S. betulifolia* *S. albus* *G. triflorum* *Thalictrum* spp.	Pfister et al. 1977 Steele et al. 1983
Picea engelmannii/ *Ribes montigenum* H.T.	Mountains of northwestern Wyoming (8,400-9,700) and southern Utah (10,000-11,400)	Cool dry	*P. engelmannii* climax	*P. contorta* *P. albicaulis* *P. flexilis* *P. tremuloides*	*R. montigenum* *F. ovina* *A. caerulea* *A. latifolia* *A. miser* *Sibbaldia procumbens*	Pfister 1972 Steele et al. 1983 Youngblood and Mauk 1985
Picea engelmannii/ *Salix pseudolapponum* H.T. [*P. engelmannii*/ *Abies lasiocarpa*/ *S. pseudolapponum* H.T.]	Mountains of northern and central Colorado (11,200-11,800)	Cool moist	*P. engelmannii* climax	*A. lasiocarpa* *P. contorta* *P. flexilis*	*S. pseudolapponum* *V. scoparium* *G. rossii* *P. pulcherrimum* (*P. delicatum*)	Hess and Alexander 1986 Hess and Wasser 1982
Picea engelmannii/ *Vaccinium caespitosum* H.T.	Mountains of northwestern Montana (3,100-5,300) and northern Utah (9,300-11,000)	Cool moist to well-drained	*P. engelmannii* climax	*P. menziesii* *P. contorta* *P. ponderosa* *L. occidentalis* *P. tremuloides*	*V. caespitosum* *L. borealis* *R. montigenum* *V. scoparium* *C. rubescens*	Mauk and Henderson 1984 Pfister et al. 1977
Picea engelmannii/ *Vaccinium myrtillus* H.T. [*P. engelmannii*/*V. myrtillus*-*Polemonium pulcherrimum* H.T.] [*P. engelmannii*/ *Vaccinium scoparium*-*P. delicatum* H.T.] *P. engelmannii* phase	Mountains of northern and southwestern New Mexico, and southern and central Colorado (9,400-11,900)	Cool dry to well-drained	*P. engelmannii* climax. *A. lasiocarpa* co-climax, minor climax or absent	*A. lasiocarpa* *P. menziesii* *P. strobiformis* *P. pungens* *P. aristata* *P. tremuloides*	*V. myrtillus* *J. americana* *J. communis* *Rosa* spp. *V. scoparium* *P. pulcherrimum* (*P. delicatum*) *Senecio amplectens*	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979 Radloff 1983

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Picea engelmannii/ *Vaccinium scoparium* H.T.	Mountains of northwestern Wyoming (8,800-10,800), north-central Wyoming (6,600-8,600), and northern Utah (9,600-11,200)	Cool dry	*P. engelmannii* climax. *A. lasiocarpa* may be minor climax	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. flexilis* *P. albicaulis*	*V. scoparium* *C. rossii* *A. cordifolia* *Antennaria* spp. *F. ovalis* (*F. virginiana*) *Lupinus* spp.	Hoffman and Alexander 1976 Mauk and Henderson 1984 Steele et al. 1983
Picea engelmannii/ *Elymus triticoides* H.T.	Mountains of southern New Mexico (9,000-9,900)	Cool dry to well-drained	*P. engelmannii* climax or co-climax with *A. lasiocarpa*. *P. menziesii* minor climax	*A. lasiocarpa* *P. menziesii* *P. aristata* *P. tremuloides*	*E. triticoides* *A. glabrum* *H. dumosis* *J. americana* *Ribes* spp.	Alexander et al. 1984a Moir and Ludwig 1979
Picea engelmannii/ *Carex disperma* H.T.	Mountains of central and southern Idaho, and northwestern Wyoming (6,000-8,000)	Cool moist	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. pungens* *P. contorta*	*C. disperma* *Actea rubra* *G. triflorum* *G. richardsonii* *Saxifraga arguta* *S. triangularis*	Steele et al. 1981, 1983
Picea engelmannii/ *Carex foenea* H.T.	Mountains of south-central Arizona (10,000-10,500)	Cool to well-drained	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*C. foenea* *B. ciliatus* *P. pratensis*	DeVelice and Ludwig 1983 Moir and Ludwig 1979
Picea engelmannii/ *Arnica cordifolia* H.T.	Mountains of northwestern Wyoming (7,500-10,000)	Cool dry to well-drained	*P. engelmannii* climax	*P. menziesii* *P. contorta* *P. flexilis* *P. albicaulis* *P. tremuloides*	*A. cordifolia* *F. idahoensis* *H. kingii* *C. rossii* *A. miser* *F. speciosa* *Senecio streptanthifolius*	Steele et al. 1983
Picea engelmannii/ *Caltha leptosepala* H.T.	Mountains of Utah (10,000-11,000), northwestern Wyoming, and southeastern Idaho (8,200-9,500)	Cool moist	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. contorta* *P. albicaulis*	*C. leptosepala* *Deschampsia caespitosa* *Arnica* spp. *Pedicularis* spp. *Phleum alpinum* *Trollis laxus* *S. triangularis*	Mauk and Henderson 1984 Steele et al. 1983
Picea engelmannii/ *Clintonia uniflora* H.T. *C. uniflora* (typic) phase *Vaccinium caespitosum* phase	Mountains of northwestern Montana (3,000-4,000)	Warm moist to well-drained	*P. engelmannii* climax	*P. menziesii* *P. ponderosa* *P. contorta* *L. occidentalis*	*C. uniflora* *Cornus canadensis* *V. caespitosum* *A. nudicaulis*	Pfister et al. 1977
Picea engelmannii/ *Equisetum arvense* H.T.	Mountains of Montana, central Idaho (2,900-6,800), northwestern Wyoming, and northern Utah (6,000-9,000)	Warm to cool wet	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. pungens* *P. contorta*	*E. arvense* *C. canadensis* *Luzula parviflora* *Equisetum scirpoides* *S. triangularis* *S. amplexifolius*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Erigeron eximius H.T.	eastern Arizona	drained	climax or	[illegible]	[illegible]	[illegible]

			A. concolor minor climax	*P. strobiformis* *P. tremuloides*	*S. stellata* *V. canadensis*	
Picea engelmannii/ *Galium triflorum* H.T.	Mountains of south-central Montana, central Idaho, and north-western Wyoming (6,000-8,500)	Cool moist	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. menziesii* *P. pungens* *P. ponderosa* *P. contorta*	*G. triflorum* *C. canadensis* *A. rubra* *S. triangularis* *S. stellata* *S. amplexifolius*	Pfister et al. 1977 Steele et al. 1981, 1983
Picea engelmannii/ *Geum rossii* H.T.	Mountains of north-central Arizona (11,200-11,800)	Cool dry	*P. engelmannii* climax	*P. tremuloides*	*G. rossii* *Festuca brachyphylla* *P. pulcherrimum* (*P. delicatum*)	Moir and Ludwig 1979
Picea engelmannii/ *Heracleum sphondyllum* H.T. (Riparian forest)	Mountains of northern New Mexico and southern Colorado (8,800-9,200)	Cool moist	*P. engelmannii* climax	*A. lasiocarpa* *P. tremuloides*	*H. sphondyllum* (*H. lanatum*) *Lonicera involucrata* *B. ciliata* *E. eximius* *G. richardsonii* *M. ciliata* *V. canadensis*	DeVelice et al. 1986
Picea engelmannii/ *Hypnum revolutum* H.T.	Mountains of central and southeastern Idaho (7,100-8,300), and north-western Wyoming (7,700-10,500)	Cool moist to well-drained	*P. engelmannii* climax or co-climax with *P. menziesii* (ID)	*P. menziesii* *P. flexilis* *P. albicaulis*	*H. revolutum* *Cladonia fimbriata* *Discranowiesia crispula* *Peltigera refescens* *S. amplexifolius* *S. triangularis*	Steele et al. 1981, 1983
Picea engelmannii/ *Saxifraga bronchialis* H.T. (Scree forest)	Mountains of northern New Mexico and southern Colorado (11,200-11,800)	Cool dry	*P. engelmannii* climax. *A. lasiocarpa* minor climax	*A. lasiocarpa* *P. tremuloides*	*S. bronchialis* *J. communis* *C. rossii*	DeVelice et al. 1986
Picea engelmannii/ *Senecio cardamine* H.T. [*P. pungens-P engelmannii/* *S. cardamine* H.T.] *Abies concolor* phase *Abies lasiocarpa* phase	Mountains of eastern Arizona and southwestern New Mexico (8,500-9,400)	Cool moist	*P. engelmannii* climax or co-climax with *A. lasiocarpa* *A. concolor* *P. menziesii*	*A. lasiocarpa* *A. concolor* *P. menziesii* *P. pungens* *P. ponderosa* *P. strobiformis*	*S. cardamine* *B. ciliatus* *G. richardsonii* *F. ovalis* (*F. virginiana*) *P. aquilinum*	Fitzhugh et al. 1987 Moir and Ludwig 1979
Picea engelmannii/ *Senecio streptanthifolius* H.T. *P. engelmannii* phase *Pseudotsuga menziesii* phase	Mountains of central and southwestern Montana (6,900-8,600)	Cool dry to well-drained	*P. engelmannii* climax	*P. menziesii* *P. flexilis*	*S. streptanthifolius* *J. communis* *A. cordifolia* *O. chilensis* *P. secunda*	Pfister et al. 1977
Picea engelmannii/ *Smilacina stellata* H.T.	Mountains of Montana east of Continental Divide (4,400-7,400)	Warm moist	*P. engelmannii* climax	*P. menziesii* *P. contorta* *P. ponderosa*	*S. stellata* *S. oreophilus* *G. richardsonii* *S. racemosa* *T. occidentale*	Pfister et al. 1977
Picea engelmannii/ *Trifolium dasyphyllum* H.T.	Mountains of north-central Colorado (10,800-11,300)	Cold moist	*P. engelmannii* climax	*A. lasiocarpa* *P. aristata*	*T. dasyphyllum* *Trisetum spicatum* *Pyrola minor* *Trifolium parryi*	Hess and Alexander 1986
Picea engelmannii/ Moss spp. H.T.	Mountains of southwestern New Mexico and eastern Arizona; Front Range, Colorado (9,500-11,000)	Cool dry to well-drained	*P. engelmannii* climax. *A. lasiocarpa* co-climax, minor climax or absent	*A. lasiocarpa* *P. menziesii* *P. strobiformis* *P. aristata* *P. tremuloides*	Moss spp. *Rosa* spp. *Ribes* spp. *Vaccinium* spp. *L. arizonicus*	Alexander et al. 1987 Fitzhugh et al. 1987 Moir and Ludwig 1979

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
			***Abies lasiocarpa* series**			
Abies lasiocarpa/ *Acer glabrum* H.T. *A. glabrum* (typic) phase *Pachistima myrsinites* phase (ID,WY)	Mountains of central and southern Idaho (5,000-8,000), northern and central Utah, northwestern Wyoming (6,000-10,000), and southwestern New Mexico (9,700-10,000)	Warm moist	*A. lasiocarpa* climax. *P. engelmannii* may be minor climax	*P. engelmannii* *P. menziesii* *P. contorta* *A. concolor* *A. grandis* *P. pungens* *P. flexilis* *P. tremuloides*	*A. glabrum* *B. repens* *P. myrsinites* *B. ciliatus* *A. cordifolia* *O. chilensis* *T. fendleri* *T. occidentale*	Alexander et al. 1987 Mauk and Henderson 1984 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ *Alnus sinuata* H.T.	Mountains of northern Montana and central Idaho (5,000-7,500)	Cool moist	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *L. occidentalis*	*A. sinuata* *V. globulare* *V. scoparium* *P. secunda* *X. tenax*	Pfister et al. 1977 Steele et al. 1981
Abies lasiocarpa/ *Berberis repens* H.T. *B. repens* (typic) phase *Picea engelmannii* phase (UT) *Pseudotsuga menziesii* phase (UT) *Pinus flexilis* phase (UT) *Juniperus communis* phase (UT) *Ribes montigenum* phase (UT) *Carex geyeri* phase (UT)	Mountains of Utah (6,000-10,800), north-western Wyoming, and southeastern Idaho (6,600-9,000)	Warm to cool well-drained	*A. lasiocarpa* climax. *P. engelmannii* minor climax	*P. engelmannii* *P. contorta* *P. pungens* *P. menziesii* *A. concolor* *A. grandis* *P. flexilis* *P. tremuloides*	*B. repens* *J. communis* *P. myrsinites* *R. montigenum* *R. woodsii* *S. oreophilus* *C. geyeri* *C. rossii*	Mauk and Henderson 1984 Pfister 1972 Steele et al. 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ *Clematis pseudoalpina* H.T.	Mountains of Montana east of Continental Divide (6,000-8,000)	Warm dry	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. flexilis*	*C. pseudoalpina* *C. tenuiloba* *A. cordifolia* *G. boreale* *Valeriana dioica*	Pfister et al. 1977
Abies lasiocarpa/ *Holodiscus dumosus* H.T. (Scree forest)	Mountains of southwestern New Mexico (9,500-10,500)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. strobiformis* *P. menziesii*. *P. engelmannii* minor climax	*P. strobiformis* *P. menziesii* *P. engelmannii* *P. tremuloides*	*H. dumosus* *J. communis* *S. oreophilus* *B. ciliatus* *G. richardsonii* *H. parryi*	Fitzhugh et al. 1987
Abies lasiocarpa/ *Jamesia americana* H.T. (Scree forest)	Mountains of south-central Arizona (8,700-9,100)	Cool dry	*A. lasiocarpa* climax	*P. menziesii*	*J. americana* *Ribes pinetorum* *Sambucus melanocarpa* *S. oreophilus*	Muldavin et al. 1986
Abies lasiocarpa/ *Juniperus communis* H.T. [*A. lasiocarpa*- *Picea engelmannii*/ *J. communis* H.T.]	Mountains of central Idaho, northwestern Wyoming (7,500-9,500), Utah, northern Arizona, southwestern New Mexico, and	Warm to cold dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *A. concolor* *P. pungens* (UT) *P. longaeva* (UT) *P. flexilis* *P. tremuloides*	*J. communis* *A. uva-ursi* *R. woodsii* *S. canadensis* *S. oreophilus* *Poa* spp. *A. cordifolia* *P. secunda*	Komarkova et al. 1988 Mauk and Henderson 1984 Moir and Ludwig 1979 Steele et al. 1981, 1983

Vaccinium scoparium phase *Xerophyllum tenax* phase (MT)	Idaho (5,000-7,500), and northwestern Wyoming (7,000-8,500)		*P. engelmannii*	*P. ponderosa* *P. monticola* *L. occidentalis* *P. tremuloides*	*C. rubescens* *A. cordifolia* *T. occidentalis* *X. tenax*	
Abies lasiocarpa/ *Menziesia ferruginea* H.T. *M. ferruginea* (typic) phase *Vaccinium scoparium* phase (ID) *Luzula hitchcockii* phase (ID) *Coptis occidentalis* phase (ID) *Xerophyllum tenax* phase (ID)	Mountains of eastern Washington, Montana, Idaho, and northwestern Wyoming (5,000-7,500)	Cool moist	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *P. albicaulis* *L. occidentalis* *T. mertensiana*	*M. ferruginea* *Ledum glandulosum* *Rhododendron albiflorum* *V. globulare* *V. scoparium* *L. hitchcockii* *C. occidentalis* *X. tenax*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/ *Oplopanax horridum* H.T.	Mountains of northern Montana (4,000-5,000)	Cool moist wet	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. monticola* *L. occidentalis*	*O. horridum* *T. brevifolia* *C. uniflora* *Tiarella trifoliata*	Pfister et al. 1977
Abies lasiocarpa/ *Pachistima myrsinites* H.T. [*A. lasiocarpa*- *Picea engelmannii*/ *P. myrsinites* H.T.(CO)]	Mountains of northern Idaho and eastern Washington (4,700-5,800), and central Colorado (9,000-9,500)	Cool to well-drained	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *L. occidentalis* *P. tremuloides*	*P. myrsinites* *V. scoparium* *C. geyeri* *A. cordifolia* *C. uniflora* *Erigeron* spp. *G. triflorum*	Daubenmire and Daubenmire 1968 Hess and Wasser 1982
Abies lasiocarpa/ *Physocarpus malvaceus* H.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern and central Utah (6,000-9,500)	Warm moist to well-drained	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *A. concolor* *A. grandis* *P. tremuloides*	*P. malvaceus* *A. alnifolia* *S. betulifolia* *Sorbus scopulina* *S. albus*	Mauk and Henderson 1984 Steele et al. 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ *Ribes montigenum* H.T. *R. montigenum* (typic) phase *Pinus albicaulis* phase (ID,WY) *Pinus contorta* phase (UT) *Trisetum spicatum* phase (UT) *Mertensia arizonica* phase (UT) *Thalictrum fendleri* phase (UT)	Mountains of southern Montana, Idaho, Utah, and northwestern Wyoming (8,000-11,000)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*R. montigenum* *T. spicatum* *C. rossii* *A. microphylla* *A. latifolia* *M. arizonica* *O. chilensis* *T. fendleri*	Mauk and Henderson 1984 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ *Rubus parviflorus* H.T.	Mountains of northern and south-western New Mexico, and southwestern Colorado (8,500-10,500)	Warm moist	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. concolor* *P. strobiformis* *P. tremuloides*	*R. parviflorus* *A. glabrum* *P. myrsinites* *V. myrtillus* *B. ciliatus* *E. eximius* (*E. superbus*) *G. richardsonii*	DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Abies lasiocarpa/ *Salix glauca* H.T. [*A. lasiocarpa*- *Picea engelmannii*/ *S. glauca* H.T.]	High mountains of south-central Colorado (11,000-11,800)	Cold wet	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii*	*S. glauca* *V. myrtillus* *Carex* spp. *Acomastylis rossii* *P. pulcherrimum* (*P. delicatum*)	Komarkova et al. 1988
Abies lasiocarpa/ *Shepherdia canadensis* H.T.	Bighorn Mountains, north-central Wyoming (8,000-8,500)	Warm dry	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*S. canadensis* *B. repens* *S. betulifolia* *V. scoparium*	Hoffman and Alexander 1976

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Abies lasiocarpa/ Spiraea betulifolia H.T.	Mountains of central and southeastern Idaho, and northwestern Wyoming (5,500-7,500)	Warm dry	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta*	*S. betulifolia* *A. alnifolia* *B. repens* *P. myrsinites* *C. rubescens*	Steele et al. 1981, 1983
Abies lasiocarpa/ Symphoricarpos albus H.T.	Mountains of southeastern Idaho and north-western Wyoming (5,700-7,600)	Warm well-drained	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. tremuloides*	*S. albus* *A. alnifolia* *C. rubescens* *A. cordifolia*	Steele et al. 1983
Abies lasiocarpa/ Vaccinium caespitosum H.T. *V. caespitosum* (typic) phase *Picea engelmannii* phase (UT)	Mountains of south-central Montana, Idaho (5,000-7,500), and northern and central Utah (8,500-10,000)	Cool moist to well-drained	*A. lasiocarpa* climax. *P. engelmannii* may be minor climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*V. caespitosum* *L. borealis* *P. myrsinites* *Ribes* spp. *V. scoparium* *C. rubescens* *A. cordifolia*	Cooper et al. 1987 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981 Youngblood and Mauk 1985
Abies lasiocarpa/ Vaccinium globulare H.T. *V. globulare* (typic) phase *Pachistima myrsinites* phase (ID,WY) *Vaccinium scoparium* phase (ID,WY)	Mountains of south-central Montana and Idaho (5,000-8,700), northern Utah, and north-western Wyoming (7,000-9,500)	Cool moist to well-drained	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis*	*V. globulare* *L. utahensis* *P. myrsinites* *R. montigenum* *S. oreophilus* *V. scoparium*	Cooper et al. 1987 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ Vaccinium myrtillus H.T. [*A. lasiocarpa-Picea engelmannii/V. myrtillus* H.T.] [*A. lasiocarpa/V. myrtillus-Linnaea borealis* H.T.] [*A. lasiocarpa/V. myrtillus-Rubus parviflorus* H.T.] [*A. lasiocarpa/ Vaccinium scoparium-L. borealis* H.T.] [*A. lasiocarpa/ V. scoparium* H.T.] *V. myrtillus* (typic) phase *P. engelmannii* phase (NM) *R. parviflorus* phase (AZ,NM)	Mountains of eastern and south-central Arizona, northern and southwestern New Mexico, southern and western Colorado (9,000-11,000), and central Utah (10,000-10,600)	Cool dry to well-drained	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. concolor* *P. pungens* *P. contorta* (CO) *P. strobiformis* *P. flexilis* *P. aristata* *P. tremuloides*	*V. myrtillus* *L. borealis* *P. myrsinites* *Ramischia secunta* *R. montigenum* *R. parviflorus* *V. scoparium* *B. ciliatus* *E. eximius* (*E. superbus*) *O. chilensis* *P. racemosa*	Alexander et al. 1987 DeVelice et al. 1986 DeVelice and Ludwig 1983 Fitzhugh et al. 1987 Hoffman 1988 Komarkova et al. 1988 Moir and Ludwig 1979 Youngblood and Mauk 1985
Abies lasiocarpa/ Vaccinium scoparium H.T. *A. lasiocarpa-Picea engelmannii/ V. scoparium* H.T. [*P. engelmannii/ V. scoparium* H.T.] *V. scoparium* (typic) phase	Mountains of Montana and Idaho (5,000-10,000) south to Arizona and New Mexico (8,000-11,000)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *L. occidentalis* *P. tremuloides*	*V. scoparium* *L. borealis* *P. myrsinites* *V. myrtillus* *C. rubescens* *C. geyeri* *A. cordifolia* *A. latifolia*	Alexander et al. 1986 Cooper et al. 1987 Daubenmire and Daubenmire 1968 Hess and Alexander 1986 Hess and Wasser

						Mauk and Henderson 1984 Moir and Ludwig 1979 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium H.T.	Mountains of Montana east of Continental Divide (7,000-9,000)	Cool dry	*A. lasiocarpa* co-climax with *P. albicaulis*	*P. albicaulis* *P. engelmannii* *P. contorta*	*V. scoparium* *C. rossii* *A. latifolia* *X. tenax* *Hieracium gracile*	Pfister et al. 1977
Abies lasiocarpa/Calamagrostis canadensis H.T. *A. lasiocarpa-Picea engelmannii/C. canadensis* H.T. [*P. engelmannii/C. canadensis* H.T.] *C. canadensis* (typic) phase *Vaccinium caespitosum* phase (ID,MT) *Galium triflorum* phase (MT) *Ledum glandulosum* phase (ID) *Ligusticum canbyi* phase (ID)	Mountains of central Montana, Idaho, northwestern Wyoming (5,000-9,000), northern Utah, and northern and central Colorado (8,000-10,500)	Cool wet	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* (ID) *P. contorta* *P. pungens* (UT) *P. albicaulis* *P. tremuloides*	*C. canadensis* *L. glandulosum* *Vaccinum* spp. *Carex* spp. *E. arvense* *G. triflorum* *L. canbyi* *S. arguta* *S. triangularis*	Cooper et al. 1987 Hess and Alexander 1986 Komarkova et al. 1988 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/Calamagrostis rubescens H.T. *C. rubescens* (typic) phase *Pachistima myrsinites* phase (ID,WY)	Mountains of Montana east of Continental Divide, Idaho, northern Utah, and northwestern Wyoming (6,000-9,000)	Cool dry	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*C. rubescens* *B. repens* *P. myrsinites* *C. geyeri* *A. cordifolia* *O. chilensis* *T. occidentale* *Viola adunca*	Cooper et al. 1987 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/Luzula hitchcockii H.T. *L. hitchcockii* (typic) phase *Menziesia ferruginea* phase (MT) *Vaccinium scoparium* phase (ID,MT)	Mountains of Montana west of Continental Divide, Idaho, and western Wyoming (6,000-8,000)	Cool well-drained	*A. lasiocarpa* climax. *P. engelmannii* *Larix lyallii* minor climaxes	*P. engelmannii* *P. contorta* *P. albicaulis* *L. lyallii* (MT)	*L. hitchcockii* *M. ferruginea* *V. scoparium* *A. cordifolia* *A. latifolia* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/Carex geyeri H.T. *A. lasiocarpa-Picea engelmannii/C. geyeri* H.T. *C. geyeri* (typic) phase *Pseudotsuga menziesii* phase (ID,MT) *Artemisia tridentata* phase (ID)	Mountains of central Montana, central Idaho, southern Utah (6,500-9,500), Wyoming, and Colorado (8,500-11,000)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*. *P. albicaulis* minor climax	*P. engelmannii* *P. menziesii* (MT,ID) *P. contorta* *P. albicaulis* *P. tremuloides*	*C. geyeri* *A. tridentata* *B. repens* *R. woodsii* *S. oreophilus* *A. cordifolia* *Lathyrus lanszwertii* *L. argenteus* *O. chilensis* *S. stellata*	Alexander et al. 1986 Hess and Alexander 1986 Hess and Wasser 1982 Hoffman 1988 Hoffman and Alexander 1976, 1983 Komarkova et al. 1988 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood and Mauk 1985

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Abies lasiocarpa/ *Carex rossii* H.T.	Mountains of southeastern Idaho, northwestern Wyoming (7,500-8,000), and central and southern Utah (8,500-10,500)	Cool dry	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. flexilis* *P. tremuloides*	*C. rossii* *A. patula* *Ribes viscosissimum* *A. cordifolia* *A. engelmannii* *A. miser*	Steele et al. 1983 Youngblood and Mauk 1985
Abies lasiocarpa/ *Aconitum columbianum* H.T.	Mountains of central and southern Utah (7,400-10,000)	Cool moist	*A. lasiocarpa* climax. *P. engelmannii* minor climax	*P. engelmannii* *P. menziesii* *A. concolor* *P. tremuloides*	*A. columbianum* *R. montigenum* *B. ciliatus* *A. rubra* *A. cordifolia* *G. richardsonii* *O. chilensis*	Youngblood and Mauk 1985
Abies lasiocarpa/ *Actaea rubra* H.T.	Mountains of central Idaho, northern Utah, and northwestern Wyoming (6,000-8,000)	Warm moist	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. pungens* *P. menziesii* *P. contorta* *A. concolor* *A. grandis* *P. tremuloides*	*A. rubra* *B. repens* *L. utahensis* *R. parviflorus* *V. globulare* *O. chilensis* *T. fendleri*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa/ *Arnica cordifolia* H.T. [*A. lasiocarpa-Picea engelmannii/A. cordifolia* H.T.] *A. cordifolia* (typic) phase *P. engelmannii* phase (ID,NW WY) *Shepherdia canadensis* phase (ID,WY) *Astragalus miser* phase (ID, NW WY)	Mountains of Montana east of Continental Divide, central Idaho, northwestern and north-central Wyoming (7,000-9,500), and south-central and western Colorado (9,000-11,000)	Cool dry to well-drained	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. flexilis* *P. tremuloides*	*A. cordifolia* *S. canadensis* *A. miser* *E. angustifolium* *F. ovalis* (*F. virginiana*) *P. secunda*	Hoffman and Alexander 1976 Komarkova et al. 1988 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/ *Arnica latifolia* H.T.	Mountains of southeastern Idaho, northern Utah, and northwestern Wyoming (7,400-9,300)	Cool dry	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*A. latifolia* *P. myrsinites* *R. montigenum* *A. engelmannii* *P. racemosa* *P. secunda*	Steele et al. 1983
Abies lasiocarpa/ *Caltha biflora* H.T.	Mountains of central Idaho (6,200-7,800)	Cool wet	*A. lasiocarpa* climax	*P. engelmannii* *P. contorta*	*C. biflora* *L. involucrata* *Dodecantheon jeffreyi* *Pedicularis bracteosa* *S. triangularis*	Steele et al. 1981
Abies lasiocarpa/ *Clintonia uniflora* H.T. *C. uniflora* (typic) phase *Menziesia ferruginea* phase *Vaccinium caespitosum* phase	Mountains of northwestern Montana, and northern and central Idaho	Warm moist to well-drained	*A. lasiocarpa* climax. Minor climaxes *A. grandis* *T. mertensiana*	*A. grandis* *T. mertensiana* *P. engelmannii* *P. menziesii* *P. contorta*	*C. uniflora* *M. ferruginea* *P. myrsinites* *V. caespitosum* *V. globulare*	Cooper et al. 1987 Pfister et al. 1977 Steele et al. 1981

				L. occidentalis	*Anemone piperi* *X. tenax*	
Abies lasiocarpa/ *Erigeron eximius* *(E. superbus)* H.T.	Mountains of southwestern Colorado, northern and southwestern New Mexico, and eastern Arizona (9,000-11,000)	Cool moist to well-drained	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. concolor* *P. pungens* *P. flexilis* *P. strobiformis* *P. tremuloides*	*E. eximius* *(E. superbus)* *B. repens* *L. involucrata* *A. cordifolia* *G. richardsonii* *L. arizonicus*	Alexander et al. 1987 DeVelice et al. 1986 Fitzhugh et al. 1987 Moir and Ludwig 1979
Abies lasiocarpa/ *Galium triflorum* H.T.	Mountains of northern Montana (5,000-7,700)	Warm moist	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis*	*G. triflorum* *A. rubra* *S. triangularis* *S. amplexifolius*	Pfister et al. 1977
Abies lasiocarpa/ *Lathyrus arizonicus* H.T.	Mountains of north-central Arizona and southwestern New Mexico (9,500-10,500)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. strobiformis* *P. tremuloides*	*L. arizonicus* *A. glabrum* *S. oreophilus* *B. ciliatus* *G. richardsonii* *S. stellata* *V. americana*	Fitzhugh et al. 1987 Moir and Ludwig 1979
Abies lasiocarpa/ *Mertensia ciliata* H.T.	Mountains of northern New Mexico and southern Colorado (9,200-11,200)	Cool moist	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides*	*M. ciliata* *Carex bella* *C. leptosepala* *Cardamine cordifolia* *M. pentandra* *O. fendleri*	DeVelice et al. 1986
Abies lasiocarpa/ *Osmorhiza chilensis* H.T. *O. chilensis* (typic) phase *Pachistima myrsinites* phase (ID)	Mountains of southeastern Idaho and northern Utah (6,500-8,800)	Warm moist to well-drained	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. flexilis* *P. albicaulis* *P. tremuloides*	*O. chilensis* *B. repens* *P. myrsinites* *C. rossii* *O. depapurata* *T. fendleri*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa/ *Pedicularis racemosa* H.T. *P. racemosa* (typic) phase *Pseudotsuga menziesii* phase (UT)	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah (7,000-9,500)	Warm dry to well-drained	*A. lasiocarpa* climax or co-climax with *P. engelmannii* (CO)	*P. engelmannii* *P. menziesii* *P. contorta* *P. flexilis* *P. albicaulis* *P. tremuloides*	*P. racemosa* *P. myrsinites* *S. oreophilus* *A. cordifolia* *A. engelmannii* *L. lanszwertii* *P. secunda*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa/ *Polemonium pulcherrimum* H.T. [*A. lasiocarpa-* *Picea engelmannii/* *P. pulcherrimum* H.T.]	Mountains of south-central Colorado (10,500-11,000)	Cool dry	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii*	*P. pulcherrimum* *(P. delicatum)* *Vaccinium* spp. *C. leptosepala* *Osmorhiza obtusa*	Komarkova et al. 1988
Abies lasiocarpa/ *Saxifraga bronchialis* H.T. (Scree forest)	Mountains of northern New Mexico and southern Colorado (10,000-11,000)	Cool dry	*A. lasiocarpa* climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. strobiformis*	*S. bronchialis* *J. communis* *R. montigenum* *K. cristata* *(K. macrantha)* *C. rossii* *F. ovalis* *(F. virginiana)*	DeVelice et al. 1986
Abies lasiocarpa/ *Senecio sanguisorboides* H.T. *S. sanguisorboides* (typic) phase *Pseudotsuga menziesii* phase	Mountains of southern New Mexico ($\geq$10,000)	Cool dry to well-drained	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. tremuloides*	*S. sanguisorboides* *R. montigenum* *Ribes wolfii* *E. eximius*	Alexander et al. 1984a Moir and Ludwig 1979

Table A1.—Continued.

Habitat type or community type	Location and elevation (feet)	Site	Successional status	Tree associates	Principal undergrowth species	Authority
Abies lasiocarpa/ Senecio triangularis H.T. [*A. lasiocarpa-Picea engelmannii/ S. triangularis* H.T.]	Mountains of central and western Colorado (9,500-11,000)	Cool wet stream bottoms	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta*	*S. triangularis* *A. cordifolia* *C. leptosepala* *E. arvense* *M. ciliata* *Streptopus* spp.	Hess and Alexander 1986 Komarkova et al. 1988
Abies lasiocarpa/ Streptopus amplexifolius H.T. *S. amplexifolius* (typic) phase *Menziesia ferruginea* phase (ID) *Ligusticum canbyi* phase (ID)	Mountains of Idaho and northern Utah (3,500-8,000)	Warm moist to wet	*A. lasiocarpa* climax. *P. engelmannii* minor climax	*P. engelmannii* *P. menziesii* *A. grandis* *P. contorta* *P. monticola*	*S. amplexifolius* *M. ferruginea* *Ribes lacustre* *L. canbyi* *S. triangularis*	Cooper et al. 1987 Mauk and Henderson 1984 Steele et al. 1981, 1983
Abies lasiocarpa/ Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming (7,600-8,900)	Warm well-drained	*A. lasiocarpa* climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*T. occidentale* *A. cordifolia* *G. richardsonii* *O. chilensis* *P. racemosa*	Steele et al. 1983
Abies lasiocarpa/ Xerophyllum tenax H.T. *X. tenax* (typic) phase *Vaccinium globulare* phase (ID,MT) *Vaccinium scoparium* phase (ID,MT) *Luzula hitchcockii* phase (MT) *Coptis occidentalis* phase (ID)	Mountains of eastern Washington, Idaho, Montana, and northwestern Wyoming (5,000-8,500)	Cool dry	*A. lasiocarpa* climax. *A. grandis* minor climax in some phases	*P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *P. albicaulis* *P. ponderosa* (MT) *A. grandis* *L. occidentalis*	*X. tenax* *V. globulare* *V. membranaceum* *V. scoparium* *L. hitchcockii* *C. geyeri* *C. occidentalis* *T. occidentalis*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa/ Moss spp. H.T. [*A. lasiocarpa-Picea engelmannii/* Moss H.T.]	Mountains of southeastern Wyoming, south-central Colorado (8,500-10,500), northern New Mexico, and south-central Arizona (9,500-11,500)	Cool dry to well-drained	*A. lasiocarpa* co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* (NM) *P. contorta* (CO) *P. aristata* *P. flexilis* *P. tremuloides*	Moss spp. *A. glabrum* *J. communis* *Rosa* spp. *V. caespitosum* *V. myrtillus*	Alexander et al. 1986 DeVelice et al. 1986 DeVelice and Ludwig 1983 Komarkova et al. 1988
Abies lasiocarpa-Pinus albicaulis H.T.	Mountains of northern Idaho and eastern Washington (≥6,000)	Cool dry	*A. lasiocarpa* co-climax with *P. albicaulis*	*P. albicaulis*	*V. scoparium* *Luzula glabrata* *C. geyeri* *X. tenax*	Daubenmire and Daubenmire 1968
***Tsuga mertensiana* series**						
Tsuga mertensiana/ Menziesia ferruginea H.T. *M. ferruginea* (typic) phase *Luzula hitchcockii* phase (ID) *Xerophyllum tenax* phase (ID)	Mountains of Montana, northern Idaho, and eastern Washington (5,000-6,500)	Cool moist	*T. mertensiana* climax or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *P. albicaulis* *L. occidentalis*	*M. ferruginea* *R. albiflorum* *V. globulare* *V. scoparium* *L. hitchcockii* *P. secunda* *X. tenax*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977
Tsuga mertensiana/ Luzula hitchcockii H.T. *L. hitchcockii* (typic) phase	Mountains of Montana west of Con[illegible]	Cool well-drained	*T. mertensiana* co-climax with [illegible]	*A. lasiocarpa* *P. engelmannii* *P. albicaulis*	*L. hitchcockii* *M. ferruginea* [illegible]	Cooper et al. 1987 Pfister et al. 1977

				P. monticola *L. occidentalis*	*V. orbiculata* *X. tenax*	
Tsuga mertensiana/ *Streptopus amplexifolius* H.T. *S. amplexifolius* (typic) phase *Menziesia ferruginea* phase *Luzula hitchcockii* phase	Mountains of northern Idaho (5,000-6,000)	Warm moist	*T. mertensiana* climax. *A. lasiocarpa* may be minor climax	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *L. occidentalis*	*S. amplexifolius* *M. ferruginea* *L. hitchcockii* *S. triangularis* *T. caroliniensis*	Cooper et al. 1987
Tsuga mertensiana/ *Xerophyllum tenax* H.T. *X. tenax* phase *Vaccinium scoparium* phase (ID) *Luzula hitchcockii* phase (ID)	Mountains of northern Idaho and northwestern Montana (5,000-6,500)	Cool dry	*T. mertensiana* climax or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. monticola* *P. contorta* *P. albicaulis* *L. occidentalis*	*X. tenax* *V. globulare* *V. membranaceum* *V. scoparium* *C. rubescens* *L. hitchcockii* *C. geyeri*	Cooper et al. 1987 Daubenmire and Daubenmire 1968 Pfister et al. 1977
			***Pinus albicaulis* series**			
Pinus albicaulis/ *Juniperus communis* H.T. *J. communis* (typic) phase *Shepherdia canadensis* phase	Mountains of southeastern Idaho and north-western Wyoming (8,000-9,800)	Cool dry	*P. albicaulis* co-climax with *P. contorta*	*P. contorta* *P. flexilis*	*J. communis* *A. uva-ursi* *S. canadensis* *A. cordifolia* *A. miser*	Steele et al. 1983
Pinus albicaulis/ *Vaccinium scoparium* H.T.	Mountains of Montana and northwestern Wyoming (8,500-10,500)	Cool dry	*P. albicaulis* co-climax with *P. contorta*. *A. lasiocarpa* *P. engelmannii* minor climaxes	*P. contorta* *A. lasiocarpa* *P. engelmannii*	*V. scoparium* *P. nervosa* *C. rossii* *A. cordifolia*	Pfister et al. 1977 Steele et al. 1983
Pinus albicaulis/ *Carex geyeri* H.T.	Mountains of Montana and northwestern Wyoming (7,500-9,500)	Cool dry	*P. albicaulis* co-climax with *P. contorta*	*P. contorta*	*C. geyeri* *F. idahoensis* *S. occidentalis* *T. spicatum* *A. millefolium* *S. multiradiata*	Pfister et al. 1977 Steele et al. 1983
Pinus albicaulis/ *Carex rossii* H.T. *C. rossii* (typic) phase *Pinus contorta* phase	Mountains of northwestern Wyoming (6,500-10,500)	Cool dry	*P. albicaulis* climax or co-climax with *P. contorta*. *A. lasiocarpa* *P. engelmannii* minor climaxes	*P. contorta* *A. lasiocarpa* *P. engelmannii* *P. flexilis*	*C. rossii* *P. nervosa* *A. cordifolia* *E. angustifolium* *L. argenteus*	Steele et al. 1983
Pinus albicaulis/ *Festuca idahoensis* H.T.	Mountains of Montana, south-eastern Idaho, and northwestern Wyoming (9,500-10,000)	Cool dry	*P. albicaulis* climax	Usually pure stands	*F. idahoensis* *O. asperifolia* *A. microphyilia* *A. miser* *L. argenteus*	Pfister et al. 1977 Steele et al. 1983
Pinus albicaulis- *Abies lasiocarpa* H.T.	Mountains of Montana and northern Idaho (≥8,000)	Cool dry	*P. albicaulis* co-climax with *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*V. scoparium* *A. latifolia* *H. gracile* *X. tenax*	Cooper et al. 1987 Pfister et al. 1977
			***Larix lyallii* series**			
Larix lyallii- *Abies lasiocarpa* H.T.	Mountains of Montana west of Continental Divide, and northern Idaho (≥8,500)	Cool dry	*L. lyallii* co-climax with *A. lasiocarpa* *P. albicaulis*	*A. lasiocarpa* *P. engelmannii* *P. albicaulis*	*P. empetriformis* *V. scoparium* *L. hitchcockii* *A. latifolia*	Cooper et al. 1987 Pfister et al. 1977

Alexander, Robert R. 1988. Forest vegetation in the Rocky Mountain and Intermountain regions: habitat types and community types. Gen. Tech. Rep. RM-162. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 47 p.

Habitat types and community types and their phases for the major forest tree species in the Rocky Mountain and Intermountain regions are tabulated. Included are the name(s), general location, elevation, relative site, successional status, principal tree and undergrowth associates, and the authority.

Keywords: Forest vegetation, classification, habitat type, community type

U.S. Department of Agriculture
Forest Service

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Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-163**

Forest Vegetation of the Gunnison and Parts of the Uncompahgre National Forests: A Preliminary Habitat Type Classification

Vera Komarkova, Robert R. Alexander, and Barry C. Johnston

USDA Forest Service
General Technical Report RM–163

August 1988

Forest Vegetation of the Gunnison and Parts of the Uncompahgre National Forests: A Preliminary Habitat Type Classification

Vera Komarkova, Research Associate
University of Colorado

Robert R. Alexander, Chief Silviculturist
Rocky Mountain Forest and Range Experiment Station[1]

Barry C. Johnston, Ecologist
USDA Forest Service, Rocky Mountain Region

Abstract

A vegetation classification based on a combination of concepts and methods developed by Braun-Blanquet and Daubenmire was used to identify 37 *tentative* forest habitat types on the Gunnison National Forest. Woodland habitat types comprised two series with a total of 3 habitat types, and forest habitat types included nine series with a total of 34 habitat types. A key to identify the habitat types is provided and the management implications associated with each are discussed.

Cover Photo.—Subalpine forests near Los Pinos Pass, Gunnison National Forest.

[1]Headquarters is in Fort Collins, in cooperation with Colorado State University.

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Forest Vegetation of the Gunnison and Parts of the Uncompahgre National Forests: A Preliminary Habitat Type Classification

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INTRODUCTION

Although forest vegetation on the Gunnison National Forest and adjacent areas had been studied previously, this study is the first attempt to comprehensively categorize and describe all forested habitat types based on quantitative data. The flora of several specific regions within the study area have been investigated. The most extensive study was by Barrell (1969), who listed the species occurring in the Gunnison Basin. Considerable research on vegetation in the Crested Butte area has been done by the Rocky Mountain Biological Laboratory in Gothic, Colo. Included in this effort were vegetation descriptions of several biotic communities (Langenheim 1962), plant succession (Barclay 1941, McCullough 1948), and general ecology of aspen communities (Morgan 1969). Adjacent to the Gunnison National Forest, Hoffman and Alexander (1980, 1983) described 11 forested habitat types each on the Routt and White River National Forests. Six of these also occur on the Gunnison National Forest. Hess and Wasser[2] also described the forested habitat types on the White River National Forest. Eight of the 18 habitat types they identified also occur on the Gunnison National Forest.

In 1982, a cooperative study, jointly funded by the Rocky Mountain Forest and Range Experiment Station and the Rocky Mountain Region, was started by Komarkova[3] to (1) identify and describe forested and nonforested habitat types on the Gunnison National Forest and part of the Uncompahgre National Forest, based on plots well distributed over the study area; (2) relate habitat types to environmental parameters; and (3) relate Gunnison National Forest habitat types to similar classifications in other Rocky Mountain forests. The habitat type classification completed in 1986 is based, in part, on concepts and methods developed by Daubenmire and Daubenmire (1968) and modified by Pfister and Arno (1980) and others, and in part on the floristic-sociological Braun-Blanquet concepts (Westhoff and van der Maarel 1978).

Although Komarkova[3] classified both forested and nonforested lands on the Gunnison National Forest, the results reported here are restricted to forest vegetation. They are intended for two primary audiences—forest managers and land-use planners who want a working tool to use on the Gunnison National Forest, and ecologists who want a research tool to use in related studies. However, many of the habitat types reported here are represented by only one or two stands and must be recognized as *preliminary*. Further intensive sampling must be conducted before results should be regarded as conclusive and before the extent of and variations within habitat types can be estimated.

[2]Hess, Karl, and Clinton H. Wasser. 1982. Grassland, shrubland, and forestland habitat types on the White River-Arapaho National Forests. (Final report, 53-82FT-1-19, on file, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)

[3]Komarkova, Vera. 1986. Habitat types on selected parts of the Gunnison and Uncompahgre National Forests. (Final report, 28K2-234, on file, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)

STUDY AREA

The study area includes the Gunnison National Forest and a small part [76,500 acres (30,970 ha)] of the Uncompahgre National Forest. This area encompasses 1,767,700 gross acres (715,670 ha) (fig. 1). The Gunnison National Forest extends southward from the Elk Mountains and White River National Forest to the San Juan Mountains adjacent to the Uncompahgre, San Juan, and Rio Grande National Forests. It extends eastward to the Sawatch Mountains and the San Isabel National Forest; westward it is bordered by the Grand Mesa and Uncompahgre National Forests and non-Forest Service lands. Elevations within the study area range from 6,440 feet (1,963 m) to Castle Peak at 14,265 feet (4,490 m).

PHYSIOGRAPHY AND GEOLOGY

The study area is geologically diverse, varying from volcanic shaped mountains and mesas in the south, predominately sedimentary rocks and granites in the north, and Precambrian and other rocks exposed by erosion in the central part of the area (Barrell 1969). Upper Cenozoic igneous rocks of the San Juan Mountains are predominately volcanic, while those of the Elk Mountains are largely epizonal plutonic; the age and sequence of petrologic types are similar in the two areas (Lipman et al. 1969). Glacial events may have occurred throughout the Holocene and may be continuing at present, as indicated by rock glaciers and small cirque glaciers (Meierding and Birkeland 1980).

The Elk Mountain Range to the north is relatively small [40 by 20 miles (64 by 32 km)] and lies in a northwest to southeast direction. Only the southern portion is included in the study area. Topography is dominated by cirques, glacial moraines, aretes, extensive talus accumulations, and rock glaciers; the latter are prevalent in areas of igneous and coarse clastic rock. Fossil and

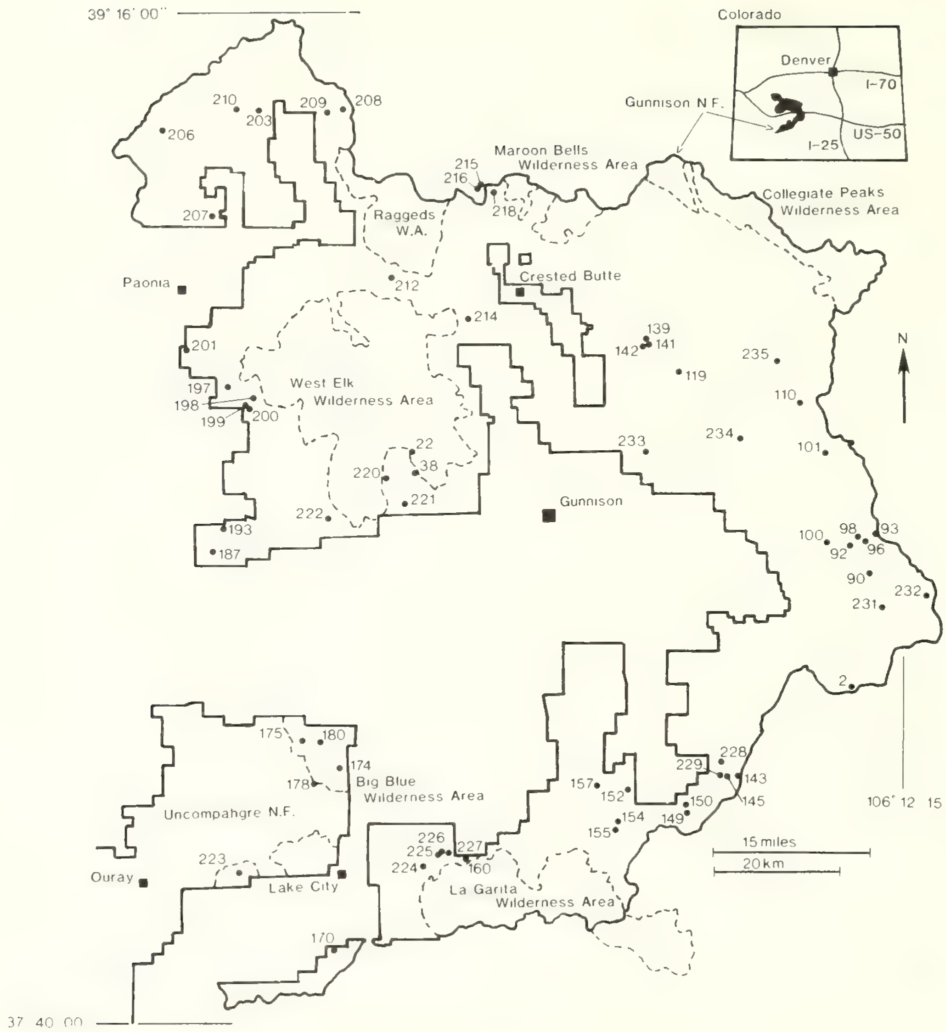

Figure 1.—Gunnison National Forest and selected parts of the Uncompahgre National Forest showing study plots.

possibly active frost features, such as stone polygons, turf-banked terraces, and rock stripes, occur. Most streams originate in cirque ice fields. Although the high erosion potential of the predominately sedimentary formations contributes to steep valley profiles, active mass wasting processes tend to obliterate them over time. Meandering stream patterns occur in thick glacial till underlying the Slate and East River valleys near Crested Butte. Rock outcrops are primarily of sedimentary origin, but igneous and metamorphic rocks also occur as surface outcroppings. The highest elevations of the Elk Mountains in the study area exceed 14,000 feet (4,270 m). These mountains are formed by steeply folded and overturned Paleozoic and Mesozoic sediments intruded by several mid-Cenozoic stocks and overridden by the Elk Range thrust carrying flat-lying Pennsylvanian, Permian Gothic, and Maroon Formations (Goodknight et al. 1981). Coarse clastic rocks occur in about 60% of the area; fine clastic rocks in about 20%; and calcareous rocks cover 6%. Igneous rocks also occur as stocks, dikes, and sills, in addition to a small area of Archean granite, gneiss, and schist. The granodiorite stock forms several rugged peaks (Mutschler et al. 1981).

In the south, the Elk Mountains consist of the Oligocene West Elk Breccia bluffs of the Gunnison River and floodplain alluvium. Some of the lower mountains are capped with Miocene basalt flows with underlying interbedded Miocene volcaniclastics. Most of the slopes are multiple debris flow complexes of coarse angular volcanic rock fragments developed in Mancos Shale. Crested Butte [12,175 feet (3,711 m) elevation] consists of a laccolith fine-grained granodiorite porphyry resting on Mancos Shale (Goodknight et al. 1981). Mount Emmons, in the Crested Butte area, includes the southern flanks of the Elk Mountains and areas of lower topography to the south and southeast. The higher peaks in the Elk Mountains have been glaciated and rise to above 12,000 feet (3,660 m) elevation. Bedrock geology is diverse and includes igneous, sedimentary, and metamorphic rocks. Surface deposits include alluvium, colluvium, talus, rock glaciers, lake deposits, glacial moraines, glacial-fluvial deposits, and slope-failure deposits (landslides, debris flows, mudflows). The latter are extensive and tend to occur in Mancos shale and shaly units of the Mesa Verde Formation, such as in Alkali Basin.

The Ruby Range area lies in the southern Elk Mountains. The immediate surroundings of Robinson Basin (north of Kebler Pass in the Lake Irwin area) rise above 13,000 feet (3,960 m) elevation in Mount Owen. Former alpine glacial episodes have left hanging valleys, U-shaped valleys, glacial striations, and other such features. The Ruby Range is formed by a series of mid-Cenozoic quartz monzonite porphyries intruded into the Mancos, Mesa Verde, Ohio Creek, and Wasatch Formations (Goodknight et al. 1981). Faulting has occurred, and talus slopes are prominent.

The Taylor River area, described by Fox and Cline (1977), is bounded on the north and east by the Sawatch Range and contains two large mountain parks (Taylor and Union). Glacial deposits that occur as moraines and outwash are extensive. North of Pitkin and in the Sawatch and Elk Mountains, alpine features occur on the higher peaks that occasionally exceed 13,000 feet (3,960 m) elevation. Stream profiles are V-shaped in unglaciated parts of the region and U-shaped elsewhere, and have steep flow gradients. There are more than 85 lakes and ponds that have been created mainly through glacial action and by beavers. The walls of Taylor River Canyon are composed of steeply dipping Precambrian metasediments and metabasalts cut by Precambrian granites, a thick sequence of metamorphics, and a series of gabbro to granite intrusions. The Mesozoic sections in the upper part are capped by Dakota sandstone. The canyon was caused by more easily eroded late Paleozoic and Mesozoic sedimentary rocks being juxtaposed against the more resistant Precambrian complex (Goodnight et al. 1981). Granite is the most extensive surface rock type in the area. It occurs as Precambrian intrusives. Other intrusive rocks are of early Tertiary age and include stocks, sills and dikes of rhyolite, quartz diorite, andesite, quartz diorite porphyry, and quartz monzonite porphyry. Metamorphic rocks are moderately extensive; they include Precambrian schist, gneiss, and granitic gneiss. The latter forms resistant outcrops and escarpments. Sedimentary rocks also occur over much of the area.

The main San Juan Mountain mass, with the exception of Mesa Seco in the northeast, was glaciated during the Pleistocene. A small glacier developed in the Powderhorn Wilderness area to the north. Fossil-patterned ground features (e.g., solifluction terraces, sorted polygons, and nets) occur. The most extensive landslide in the Basin occurred west of Slumgullion Pass. Saturated surface bedrocks moved towards the west, possibly during late glacial or neoglacial time to create a large earthflow complex in the vicinity of Lake City (Trench 1978). A collapsed caldera also occurs near Lake City. At Cochetopa Creek, there are outcrops of Precambrian, weakly metamorphosed, pyroclastic felsic volcanic rocks. The central part of the Cochetopa Park caldera is dominated by Cochetopa Dome, which is a complex of quartz latitic lava (Goodknight et al. 1981). Volcanism persisted in the San Juan Mountains long after it had ended in the West Elk Mountains (Hansen 1981). The Mesa Seco Plateau is situated in an area subject to repeated volcanism, erosion, and uplift. Surface rocks are mainly Tertiary volcanics, but older Precambrian metamorphosed schists and gneisses occasionally outcrop, as well as sedimentary rocks of Paleozoic, Mesozoic, and Tertiary ages. Volcanic eruptions and flows in these mountains commenced in the Miocene and ended in the Pliocene, or even early Pleistocene, with the cessation of the Hinsdale Formation episode. Mesa Seco is capped by Hinsdale latite-basalt and underlain by Hinsdale rhyolite and an older rhyolite (Johnson 1970).

The higher West Elk Mountain Peaks in the south represent a center of volcanic activity, somewhat comparable in time to activity in the San Juan Mountains (Gaskill et al. 1981). Intrusive rocks (grandiorite plutons) penetrated sedimentary and other bedrock in parts of the Elk, Ruby, and West Elk Ranges in early-Middle Oligocene time, forming laccoliths, such as Tater Heap and Mount Gunnison [12,719 feet (3,876 m) elevation]. The Castles on West Elk Peak [13,035 feet (3,973 m) elevation] are composed of stratified West Elk breccia, a series of andesitic volcanoclastic rocks (Goodknight et al. 1981). One of the more unusual features of the region is the volcanic dome and swarms of radial dikes near the center of volcanic activity in the West Elk Wilderness. In addition to formations mentioned above (Dakota, Morrison, Mesa Verde, and Mancos shale), several others predate the volcanism of mid- to late-Tertiary periods. The oldest of these is the Entrada Sandstone (Jurassic) and the youngest sedimentary formation in the area is the Wasatch (Eocene and Paleocene). Widespread landslides and earthflows occur extensively in western and northeastern boundaries of the West Elk volcanic field (Soap and West Elk Creeks, and the Black Canyon of the Gunnison River). The mesas north of the Black Canyon of the Gunnison are part of the Gunnison uplift still capped by the Dakota sandstone (Hansen 1981). Black Mesa, the western extremity of the Elk Mountains, is capped by a layer of volcanic material, principally Piedra rhyolite and Huerta andesite (Paulsen 1969). A cycle comparable to the Miocene Hinsdale (described above) occurred in the area. Prior to that, an extensive outflow of welded and nonwelded ashflow tuffs were ejected to form various units of the West Elk breccia.

CLIMATE

Temperature and precipitation data are available from numerous climatic stations in or near the study area (U.S. Department of Agriculture, Weather Bureau 1930; U.S. Department of Commerce, Weather Bureau 1952, 1964). Additional climatic data also are available from the literature; for example, snow depth measurements in the East River Valley (Langenheim 1953), and snow depth and water content measurements for Slumgullion Pass (Johnson 1970). Limited climatic data also have been collected at the Rocky Mountain Biological Laboratory at Gothic and at the Black Mesa Experimental Area near Cimarron.

Climatic records indicate a considerably warmer and drier weather in the center of the Gunnison Basin and

in its southern part than in the north and at the perimeter of the Basin. In part this is an effect of higher elevations at the perimeter. For example, a very humid and cold climate occurs at a weather station near Independence Pass at 10,500 feet (3,200 m) elevation, just outside the study area. However, there also is a clear north-south gradient from humid to drier climate at similar elevations (Crested Butte versus Lake City). Precipitation is highest locally at Ruby and Marble (near Gothic). These areas have fairly high precipitation, even when compared to other Colorado mountain stations. The Paonia area, which is outside of the basin and at the lowest elevation included in the study, shows the driest weather because of the influence of the climate in the dry western part of Colorado (U.S. Department of Commerce, Environmental Science Services Administration 1968). Precipitation is higher at comparable elevations in the Gunnison National Forest than on the East Slope of the Rocky Mountains, because it is on the windward side of the moisture-bearing Pacific air masses. Higher elevations in the East River area (near Gothic and Crested Butte) may have an annual mean precipitation as high as 41 inches (104 cm).[4] Low precipitation totals in January and February at Taylor Park may reflect low moisture content of snow in that very cold area. The second lowest temperature [–60°F (–51°C)] recorded in Colorado was measured in Taylor Park in 1951. Average annual snowfall varies from 52 inches (132 cm) at Cochetopa Creek to 211 inches (536 cm) near Sapinero and at Crested Butte. Snowfall probably is higher in the mountains but no records are available. The average growing season in Gunnison County is 49 days. Temperature inversions occur almost daily in the mountain valleys.

The temperature and precipitation data from published records are useful in characterizing the Gunnison National Forest in broad, general terms. However, in regions with massive mountain ranges, deep valleys and canyons, and high plateaus, precipitation and temperatures are so variable that it is difficult to provide any meaningful climatic information for a given locality, without on-site climatic data.

ECOLOGICAL TERMS AND CONCEPTS

Because terminology in ecology is not uniformly used or understood, the terms and concepts used in this paper are defined. Unless stated otherwise, all terms follow usage proposed by Daubenmire and Daubenmire (1968).

The fundamental unit of plant community classification is the "plant association," defined as the climax plant community that is "represented by stands occurring in places where environments are so closely similar that there is a high degree of floristic uniformity in all layers" (Daubenmire 1978). Forested plant associations are distinguished from one another primarily on the basis of the tallest tree layers, and secondarily on the basis of undergrowth vegetation. For example, *Populus tremuloides* is widely distributed as a seral and climax tree species in Colorado. Where it is climax, several combinations of undergrowth species occur. The most luxuriant combination is one characterized by *Thalictrum fendleri*, which usually also includes *Carex geyeri*. On some climax sites, however, the more luxuriant forbs are absent and the undergrowth is dominated by *C. geyeri* alone; these stands belong to the *P. tremuloides/C. geyeri* plant association. Thus, *P. tremuloides/T. fendleri* and *P. tremuloides/C. geyeri* are two distinct plant associations, although *C. geyeri* may be present in both.

Plant associations are grouped together into a "plant series" based on the same climax dominant overstory species. For example, all plant associations having *Pinus ponderosa* as a climax dominant are grouped into the *P. ponderosa* series. The series is more than an artificial grouping of habitat types using the potential climax overstory dominant as the convenient thread of continuity. There is an ecological basis for grouping habitat types into series. For example, *Pinus ponderosa* occupies areas warmer and drier than areas where *Pseudotsuga menziesii* is climax. Continuing higher into the mountains, *Populus tremuloides, Pinus contorta*, and *Abies lasiocarpa* and *Picea engelmannii* successively become the dominant species.

The "habitat type" is the fundamental unit of classification of land into sites based on their potential (climax) natural vegetation. A habitat type represents all parts of the landscape that support, or have the potential to support, the same climax plant association (Daubenmire 1978, Daubenmire and Daubenmire 1968). Therefore, one habitat type corresponds to only one plant association; each habitat type is named for the plant association which describes its potential.

A climax plant association is that plant community which has attained a steady state with its environment. Without disturbance, plant species of climax vegetation successfully maintain their population sizes or regularly fluctuate around a stable equilibrium (Daubenmire 1978). When different climax plant associations are compared, it can be seen that there are different relationships between vegetation and environment that lead toward and maintain the climax. Tansley (1935) originally proposed distinguishing between different kinds of climax, called "climatic," "edaphic," and "physiographic climaxes;" he also discussed "fire" and "biotic climaxes." Daubenmire (1952) used this approach with minor modifications in his classification of forest vegetation in the northern Rocky Mountains. Daubenmire (1968) and Daubenmire and Daubenmire (1968) further elaborated on the definition, usage, and limitations of this approach, called the "polyclimax concept." A "climatic climax" association develops on normal topography with fairly deep, well-drained, loamy soil. The absence of recurring disturbance is also critical in defining climatic climax vegetation. Where soils or topography exert sufficient influence to produce self-perpetuating vegetation distinct from the climatic climax, the terms "edaphic climax" and "topographic climax," respectively, are used to describe the steady-state plant association. Where special topographic con-

[4]*Unpublished data on file, Gunnison National Forest.*

ditions also favor the development of edaphic conditions distinct from the normal, the term "topoedaphic climax" is often used to describe the resulting steady-state plant association.

Where recurring disturbance, such as grazing or fire, has a predominant influence on succession and on the resulting steady state, the term "disclimax" is used. Two common disclimaxes are the "zootic climax" and the "fire climax." If the disturbances responsible for the disclimax are removed, the vegetation may revert to the primary climax.

"Seral" vegetation is that which has not attained a steady state; current populations of some species are being replaced by others. In some instances, trends toward the climax vegetation can be identified; in others, these trends are not evident; and in still others, the vegetation may not attain the climax. The term "community type" has been used to identify vegetation which may be either (1) climax, but about which there is uncertainty, or (2) seral, but the trend toward climax is not evident. Moreover (3), the recognized plant community in place varies at any given time. Community types have one or more overstory dominants and characterisitic undergrowth species. The undergrowth may be climax, but the overstory dominants are often long-lived, seral species that may be self-perpetuating because of repeated disturbance that prevents or slows down the succession to climax vegetation.

In the absence of adequate climatic data for the Gunnison National Forest, it is assumed that the self-perpetuating, climax populations of dominant trees are related to the macroclimate, soils, and past disturbances. Stands within a plant association usually have the same general appearance whether they are on the Gunnison National Forest or in nearby forests of Colorado (DeVelice et al. 1986; Hess and Wasser;[2] Hoffman and Alexander 1980, 1983).

The Gunnison National Forest has been disturbed by fire, logging, diseases, insects, and grazing for many years. Because of these disturbances, most of the forested land area currently does not support climax vegetation. Much of the area occupied by a habitat type may never attain the climax stage. Nevertheless, the land units called habitat types best represent the units that reflect each site's potential. It is important to consider sites in terms of their potential status, because classification by potential vegetation results in the most significant biogeographic classification of the land surface (Daubenmire 1952). The practical value of habitat type classifications is only beginning to be realized in activities such as mapping tree productivity; disease and insect susceptibility; potential for producing forage, browse and cover; soil moisture; and tree regeneration (Arno and Pfister 1977; Daubenmire 1961, 1973; Layser 1974; Monsured 1984; Pfister 1972). The habitat type concept offers a useful approach to classifying and managing forest resources.

METHODS

During 1982 and 1983, a systematic survey was made through all vegetation types to select mature, relatively undisturbed stands across as many environmental gradients as possible. The choice of the stands—partly based on historical records, maps, and aerial photographs, but mainly on on-the-ground investigation—was done subjectively but without preconceived bias—a method recommended by Mueller-Dombois and Ellenberg (1974). At each sampling site, plants present were listed, their cover and abundance were noted, and successional status of the stand and dominant tree species were estimated. For each study site brief descriptions, including physiographic factors and soil features, were noted. In addition, potential sampling sites were marked on topographic maps and photographed. The first approximation of potential habitat types was made by analysis of the first year's data.

During the summers of 1982 and 1983, 65 woodland and forest stands also were sampled somewhat more intensively. The forest stand sample was small because of the time devoted to sampling nonforest vegetation. The primary emphasis in the 65 forest stands was on sampling climax zonal vegetation (consisting of relatively undisturbed stands), with secondary emphasis on azonal vegetation (vegetation sustained by natural or human disturbance, such as grazing). The least emphasis was placed on successional vegetation (vegetation recovering after infrequent disturbance of varying intensity, such as fire or cutting). Stands were representative of forest and woodland communities characterized by the following species: *Juniperus osteosperma*, *Quercus gambelii*, *Pinus ponderosa*, *Pseudotsuga menziesii*, *Picea pungens*, *Pinus flexilis*, *Pinus contorta*, *Populus angustifolia*, *Populus tremuloides*, *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus aristata*.

In stands sampled, plots varying in size from 215 square feet (20 m^2) to 4,036 square feet (375 m^2) were established (actual size for each plot is shown in appendix tables). The diameters of all trees, within selected plots only, beginning with the 2-inch d.b.h. (5 cm) class, were measured at breast height and recorded by 0.328-foot (1-dm) classes. All trees less than the 2-inch d.b.h. (5 cm) class were recorded by three height classes—0 to 24 inches (0 to 60 cm), 24 to 94 inches (61 to 240 cm), and >94 inches (>240 cm).

To determine cover for each undergrowth species, percentage cover was estimated for each species present on the entire plot using the Braun-Blanquet floristic-sociological concept (Westhoff and van der Maarel 1978). This method differs from the standard Daubenmire methodology which divides each plot into three subplots.

At each location, soil profiles, depths, and properties were determined, and a soil sample taken from each horizon. The pH values were determined in saturated paste in the laboratory. Soil profiles were described (Komarkova[3]) according to standard soil taxonomy (U.S. Department of Agriculture, Soil Survey Staff 1975). It is not possible to assign these soils to taxonomic classes because sampling was not deep enough.

Tree size class data, for those plots where the data were collected, were combined according to habitat type, and mean values for each size class within each habitat type were calculated (table A–1).

For each plot examined, the actual percentage of cover estimated for each shrub, graminoid, and forb species is shown in appendix tables A–2 through A–8. Tabulated cover by species and selected site and stand characteristics were arranged and rearranged to group stands with similar floristic composition and climax tree species using the Braun-Blanquet methodology (Westhoff and van der Maarel 1978). Differences between this and Daubenmire's (1952) approach are minor. Tabulation of data and rearrangement of association tables to arrive at habitat types and their indicator species groups are similar, and both approaches utilize numerical methods to analyze vegetation and environmental data (Franklin et al. 1970, Pfister and Arno 1980). Initial habitat type separation was based on consideration of tree overstory and major undergrowth shrubs, graminoids, and forbs (Mueller-Dombois and Ellenberg 1974).

The habitat types initially partitioned by this methodology were quantitatively verified using a combination of numerical methods. Similarity indexes were used to determine whether the initial habitat type delineation was justified on either a floristic or environmental basis (Mueller-Dombois and Ellenberg 1974). DECORANA (a detrended correspondence analysis based on reciprocal averaging) was used to portray the relationship of habitat types to environmental gradients in the ordination space (Hill 1979). Thirty-seven habitat types in 11 series were delineated by this multitiered analysis. Because many habitat types are represented by only one or two stands, the habitat types are recognized as tentative until confirmed by more intensive sampling. However, many of the habitat types identified here have been described on the surrounding National Forests (Hess and Wasser;[2] Hoffman;[5] Hoffman and Alexander 1980, 1983). Johnston (1987) also recognized many of these habitat types in his Plant Associations of the Rocky Mountain Region.

Nomenclature for plants collected in this study follows Weber (1987). Although plants were collected at various times during the growing season, some taxonomic difficulties persisted. Most of these resulted from hybridization among two or more species that have not been studied systematically to clarify the taxonomy. Other taxonomic difficulties related to lack of flowering specimens. Where considerable variation made it impossible to determine species, only genera were used.

WOODLAND HABITAT TYPES

Woodland vegetation in the Gunnison National Forest consists of the *Juniperus osteosperma*- and *Quercus gambelii*-dominated vegetation at the warmer, drier low elevations.

JUNIPERUS OSTEOSPERMA SERIES

The *Juniperus osteosperma* series does not occur in the Gunnison Basin and is rare on the Paonia District. Most stands in this series are located at low elevations outside the Gunnison National Forest boundary, except for the lower west-facing slopes of Landsend Peak. These are some of the warmest and driest sites in the foothill and lower montane zones of the study area (table 1). The *Juniperus osteosperma* series is closely related to the *Pinus edulis* series described by DeVelice et al. (1986), Francis (1986), and Moir and Carlton (1987).

The *J. osteosperma* series is represented by only one plot in a stand around Todd Reservoir at an elevation of 7,162 feet (2,183 m). Tree size data are not available for this series. Plant species data for *J. osteosperma* stands are shown in table A–2. Distribution of habitat types within this series in the western United States is poorly known, because *Juniperus*-dominated stands are not included in many forest habitat type studies.

Juniperus osteosperma/Symphoricarpos oreophilus

Description.—The *Juniperus osteosperma/Symphoricarpos oreophilus* habitat type, originally described by Komarkova[3] as a *J. osteosperma/Mahonia fremontii* habitat type, was sampled in only one small stand on the Paonia District on a gentle (5%), exposed, rocky, southeast-facing slope. Soils in this stand, derived from limestone, vary from a loamy sand to a sandy loam (table 1). Other stands in this habitat type occur below the Gunnison National Forest boundary.

Open-grown *Juniperus osteosperma* dominates the overstory. *Pinus edulis* was absent in the stand sampled. Undergrowth is dominated by *Symphoricarpos oreophilus* (65% cover) (fig. 2). There is some evidence that the prevalence of *S. oreophilus* may be the consequence of repeated fires, but there is no evidence that it is being replaced in the stand sampled. Other important shrubs are *Mahonia fremontii* and *Rosa woodsii*. However, *M. fremontii* is a rare species in Colorado, being more common in the Southwest; consequently it is not a good indicator species in Colorado. Grazing also probably significantly affected the herbaceous layer, which is dominated by *Carex geyeri* and *Bromus tectorum*. Other important graminoids are *Poa nemoralis* ssp. *interior* and *Stipa pinetorum*. The forb layer contains a number of species, but cover of individual species is low. Major forbs include *Achillea lanulosa, Galium septentrionale, Senecio serra, Thalictrum fendleri*, and *Viola canadensis*.

Although *J. osteosperma* is widespread throughout the southern Rocky Mountains, the *J. osteosperma/S. oreophilus* habitat type has not been previously reported in Colorado (Alexander 1987) or elsewhere. Hess and Wasser[2] reported a very different *J. osteosperma/Cercocarpus montanus* habitat type on the White River National Forest. The *J. osteosperma/S. oreophilus* habitat type also seems to be related to the *Pinus edulis/Quercus gambelii-Carex geyeri* habitat type described by Hess and Wasser[2] on the White River National Forest.

Management implications.—This very dry habitat has low potential for fuelwood production because growth is very slow and trees are widely spaced. Livestock

[5]*Personal correspondence with Dr. George R. Hoffman, University of South Dakota, Vermillion, S. Dak.*

Table 1.—Selected topographic and edaphic characteristics in the Gunnison National Forest.

Habitat type	Number of stands sampled	Elevation (m)	Soil texture	Depth sampled (cm)	pH
Juniperus osteosperma/Symphoricarpos oreophilus	1	2183	Sandy loam-loamy sand	7–17	7.9
Quercus gambelii/Amelanchier alnifolia	2	1963-2929	Sandy loam-clay	17–60	6.1–7.1
Quercus gambelii/Prunus virginiana	1	2793	Sandy loam	8–15	6.5
Pinus ponderosa/Festuca arizonica	2	3012-3030	Sandy loam	28–50	7.1
Pinus ponderosa/Festuca idahoensis	1	2670	Sandy loam-loam	10–20	7.1
Picea pungens/Festuca arizonica	2	2973-3014	Sandy loam-sandy loam	--	--
Picea pungens/Amelanchier alnifolia	2	2039-2407	Sandy loam-loam	12–60	6.2–6.5
Pseudotsuga menziesii/Purshia tridentata	2	2829-2988	Sandy loam-loam	16–60	6.3–7.2
Pseudotsuga menziesii/Jamesia americana	1	2988	Loam	6–15	7.4
Pseudotsuga menziesii/Paxistima myrsinites	1	3024	Sandy loam	--	--
Pseudotsuga menziesii/Symphoricarpos oreophilus	2	2720-2836	Sandy loam-loam	31–82	6.2–7.5
Pseudotsuga menziesii/Carex geyeri	2	2426-2975	Sandy loam	--	--
Pseudotsuga menziesii/Festuca idahoensis	1	3024	Sandy loam	13–15	7.4
Populus tremuloides/Amelanchier alnifolia-Prunus virginiana	2	2450-2456	Loamy sand-sandy loam	11–30	6.2
Populus tremuloides/Symphoricarpos oreophilus	3	2554-2842	Sandy loam	17–52	6.1–7.3
Populus tremuloides/Festuca arizonica	1	2973	Sandy loam	12–31	6.3
Populus tremuloides/Pteridium aquilinum	2	2573-2682	Sandy loam-loam	10–18	7.3
Populus tremuloides/Thalictrum fendleri	1	3049	Loam	8–10	7.2
Populus tremuloides/Arctostaphylos adenotricha	1	3186	Loam	44–60	6.5
Populus tremuloides/Festuca thurberi	3	3164-3170	Sandy loam	27–30	6.7–6.9
Populus angustifolia/Alnus incana-Swida sericea	1	2186	Sandy loam	0–10	6.6
Pinus contorta/Juniperus communis	2	2636-3243	Sandy loam	25–30	6.0
Pinus contorta/Vaccinium scoparium	1	3250	Sandy loam	50–80	5.8
Pinus contorta/Carex geyeri	1	2361	Sandy loam	--	--
Pinus flexilis/Ciliaria austromontana	1	2744	Sandy loam	7–23	6.9
Pinus aristata/Festuca thurberi	1	3616	Loam	30–62	7.7
Pinus aristata/Festuca arizonica	5	2878-3042	Sandy loam-loam	6–38	6.0
Pinus aristata/Juniperus communis	1	3060	Sandy loam	15–30	6.4
Abies lasiocarpa/Juniperus communis	2	3152-3195	Sandy loam	7–30	6.4–6.7
Abies lasiocarpa/Vaccinium myrtillus	3	2850-3517	Sandy loam-loam	3–60	5.9–6.4
Abies lasiocarpa/Vaccinium scoparium	1	3231	Sandy loam	--	--
Abies lasiocarpa/Carex geyeri	4	2693-3282	Sandy loam-loam	7–25	6.0–7.0
Abies lasiocarpa/Calamagrostis canadensis	1	2720	Loam	38–50	6.6
Abies lasiocarpa/Polemonium pulcherrimum	2	3228-3369	Sandy loam	4–12	6.0
Abies lasiocarpa/Arnica cordifolia	2	2845-3314	Loam	15–20	6.3
Abies lasiocarpa/Senecio triangularis	1	3075	Sandy loam-loam	--	--
Abies lasiocarpa/Moss spp.	3	2970-3219	Sandy loam	11–29	5.3–6.5

Figure 2.—*Juniperus osteosperma/Symphoricarpos oreophilus* habitat type at Todd Reservoir, Paonia District. *S. oreophilus*, *Mahonia fremontii*, *Bromus tectorum*, and *Carex geyeri* dominate the undergrowth in this stand.

forage production is low. The *J. osteosperma/S. oreophilus* habitat type is moderately important as mule deer winter range because *S. oreophilus* can be a significant food source. Overstory trees adjacent to grasslands may provide cover for a variety of wildlife. This habitat type has no potential for increasing water production but it provides watershed protection. Its potential for developed and dispersed recreation is low.

Fire, which can be an effective tool for regenerating *Juniperus*-dominated stands, plays an important role in maintaining them. *Juniperus* taller than 4 feet (1.2 m) are moderately resistant to fire. *Symphoricarpos oreophilus* sprouts prolifically after fire, especially a "cool" surface fire. These shrubs probably would assist in carrying a fire in this habitat type because they are less resistant to fire than *Juniperus* (Wright et al. 1979).

QUERCUS GAMBELII SERIES

Quercus gambelii occupies a zone between the *Artemisia tridentata*-dominated shrub-steppe and the

wetter forest habitat types at higher elevations usually dominated by *Populus tremuloides*. In the Gunnison Basin, *Q. gambelii*-dominated vegetation usually occurs at elevations that are below the Gunnison National Forest boundary, but in the Paonia District, it forms a fairly wide belt at elevations just above the forest boundary. *Q. gambelii* may occur as a small tree and a shrub. For example, shrub *Q. gambelii* frequently dominates shrublands with several associated shrubs. In other locations, small-statured *Q. gambelii* forests with a recognizable undergrowth develop. Most of the *Quercus*-dominated stands have been grazed to varying degrees. In this series, descriptions of vegetation and management implications provided by Steinhoff[6] and Kufeld (1983) apply to the western part of the Gunnison National Forest.

The *Q. gambelii* series is represented by three plots and two habitat types located at elevations ranging from 6,440 to 9,610 feet (1,963 to 2,929 m) (table 1). Plant species data for *Q. gambelii*-dominated stands are shown in table A–2. Distribution of habitat types in this series in the western United States is poorly known, because *Q. gambelii*-dominated stands are excluded from many forest habitat type studies.

Quercus gambelii/Amelanchier alnifolia

Description.—The *Quercus gambelii/Amelanchier alnifolia* habitat type was sampled in two stands; one stand is in the vicinity of Long Gulch, near Black Mesa on the Paonia District, on a moderate (27%) southeast-facing slope. The second stand is in Hubbard Creek Canyon, Paonia District, on a moderate (27%) east-facing slope. Stand 207 was originally classified by Komarkova[3] as a *Q. gambelii/Prunis virginiana-Paxistima myrsinites* habitat type. The soils in the two stands range from a sandy loam to a loamy sand (table 1). Within the habitat type, slopes are steep; soils are coarse, deep, and not drained well enough to support trees.

The overstory is dominated by *Quercus gambelii*, which also may occur in the undergrowth. This habitat type characteristically appears as a mixture of tall- and medium-height shrubs, but the undergrowth is dominated by *Amelanchier alnifolia* (6–15% cover) (fig. 3). *Acer glabrum* (stand 207), *Mahonia repens, Paxistima myrsinites* (stand 207), *Prunus virginiana, Rosa woodsii, Swida sericea* (stand 207), and *Symphoricarpos oreophilus* are important shrub associates. The most important herbaceous species present are *Bromis pumpellianus, Carex geyeri, Elymus trachycaulus, Achillea lanulosa, Galium septentrionale, Heliomeris multiflora, Lathyrus leucanthus, Linum lewisii, Lomatium dissectum, Osmorhiza depauperata*, and *Smilacina stellata*.

The *Q. gambelii/A. alnifolia* habitat type has not been identified previously in the Rocky Mountains by investigators using standard habitat type methodology, but a *Q. gambelii/A. alnifolia* plant community with similar

[6]*Steinhoff, Harold W. 1978. Management of Gambel oak associations for wildlife and livestock. (Report.) Rocky Mountain Region, Denver, Colo.*

Figure 3.—*Quercus gambelii/Amelanchier alnifolia* habitat type near Long Gulch, Black Mesa. *A. alnifolia, Prunus virginiana, Symphoricarpos oreophilus, Carex geyeri*, and *Lathyrus leucanthus* have high coverage in this stand.

characteristics has been identified in western Colorado (Bunin 1975, Steinhoff[6]). A number of the undergrowth species in the *Q. gambelii/A. alnifolia* habitat type are also present in the *Q. gambelii/S. oreophilus* habitat type, where *A. alnifolia* is a codominant, identified on the Grand Mesa, Routt, White River and Uncompahgre National Forests to the north and west of the Gunnison National Forest (Hess and Wasser;[2] Hoffman;[5] Hoffman and Alexander 1980, 1983). A *Q. gambelii/S. oreophilus* plant community is also widespread through the northern Great Basin. The close relationship between the *Q. gambelii/A. alnifolia* and *Q. gambelii/S. oreophilus* habitat types suggests that additional sampling will be required to determine whether separation into two habitat types is justified.

Management implications.—*Quercus gambelii* is a clonal species that sprouts vigorously following clear-cutting, spraying, burning, etc. Consequently, most attempts to control *Q. gambelii* have failed. Thinning individual clumps to increase acorn production, however, usually releases the residual stems so they can grow to larger sizes. Moreover, since sprouting is not much stimulated by thinning, it usually creates a *Quercus* "savanna," with improved livestock and wildlife forage and cover. Visual values are also maintained and/or improved.

Q. gambelii has high value as fuelwood in some localities (Wagstaff 1984). Cutting usually is a small-scale operation with light equipment. Burning increases *Q. gambelii* and decreases other shrubs in the first 10 years after treatment. Total forb, graminoid, and other shrub production initially increases, then decreases between 2 and 5 years after burning, followed by another increase 10 years after treatment (Kufeld 1983). Most birds and mammals are tolerant of or indifferent to burning, but *Accipiters* and shrub-nesting birds are intolerant of hot burns (Steinhoff[6]).

Grazing decreases graminoid and forb cover and has the effect of increasing *Q. gambelii* at the expense of *A. alnifolia*. *Q. gambelii* stands that have aggressively

sprouted create difficult access for grazing animals. The *Q. gambelii/A. alnifolia* habitat type has high potential for deer and elk spring-fall range and may be an important component of winter range. Hiding cover can be variable, and there is often a large quantity of palatable shrubs for big game (Kufeld 1983, Steinhoff[6]). High priority should be placed on protecting and/or improving this habitat type where stands are in or near big game winter range.

Quercus gambelii/Prunus virginiana

Description.—The *Quercus gambelii/Prunus virginiana* habitat type, originally classified as a *Q. gambelii/Symphoricarpos oreophilus* habitat type by Komarkova,[3] was sampled in one small stand in Buckhorn Gulch, near Black Mesa on the Paonia District. The sampled stand is on a gentle to moderate (11%) slope, with a southeast-facing aspect. Soils are fairly deep, well-drained sandy loams (table 1). This habitat type normally occurs on lower to middle slopes with coarse, well-drained soils where moisture availability limits stand extent. *Populus tremuloides* occurs occasionally with *Quercus gambelii* in the overstory. The undergrowth is dominated by the tall shrub *Prunus virginiana* (15% cover) (fig. 4). Other important shrubs include *Mahonia repens* and *Symphoricarpos oreophilus*. Important graminoids are *Carex geyeri*, *Festuca thurberi*, and *Stipa nelsonii*. The forb layer is dominated by *Conioselinum scopulorum*, with *Lathyrus leucanthus* present in significant amounts.

The *Q. gambelii/P. virginiana* habitat type was identified previously on the White River National Forest by Hess and Wasser.[2] This habitat type is related to the *Q. gambelii/A. alnifolia* habitat type, but differs in the absence of *A. alnifolia*, *Elymus trachycaulus*, and *Smilacina stellata* and the high coverage of *Festuca thurberi* and *Conioselinum scopulorum* in the stand sampled. The *Q. gambelii/P. virginiana* habitat type also appears to be related to the *Q. gambelii/Symphoricarpos oreophilus* habitat type identified on the Grand Mesa,

Figure 4.—*Quercus gambelii/Prunus virginiana* habitat type near Buckhorn Gulch, Black Mesa. *P. virginiana, Carex geyeri, Festuca thurberi*, and *Conioselinum scopulorum* have high coverage.

Routt, White River and Uncompahgre National Forests (Hess and Wasser;[2] Hoffman;[5] Hoffman and Alexander 1980, 1983). Considerably more sampling will be required to identify and describe the *Q. gambelii*-dominated habitat types on the Gunnison National Forest.

Management implications.—The management implications of the *Q. gambelii/P. virginiana* habitat type are similar to those of the *Q. gambelii/A. alnifolia* habitat type, except that this habitat type has higher value for early season livestock grazing where there is significant cover of *Festuca thurberi*.

FOREST HABITAT TYPES

Forest vegetation on the Gunnison National Forest ranges from the *Pinus ponderosa*-dominated vegetation at the lower, drier elevations to the *Abies lasiocarpa-Picea engelmannii*-dominated vegetation at the cooler, moister high elevations.

PINUS PONDEROSA SERIES

The *Pinus ponderosa* series occurs infrequently at the lower elevations between forest and nonforest vegetation on the Gunnison National Forest. Some investigators have concluded that *P. ponderosa* is being eliminated from the Gunnison Basin, because there was no recruitment in the reproduction classes (Barrell 1969). However, the current study indicated that some *P. ponderosa* reproduction is occurring. In any case, *P. ponderosa* has always been a minor component of the coniferous forest zone in the Gunnison Basin. The series occurs on southeast to easterly aspects at elevations ranging from 8,760 to 9,880 feet (2,670 to 3,012 m), within environments that, while dry, are moister than in the *Juniperus*- and *Quercus*-dominated vegetation (table 1).

The *P. ponderosa* series was sampled on three plots, representing two habitat types. Tree sizes on the one plot where they were measured ranged from the 2- to 4-inch (0.5- to 1-dm) to the 24- to 28-inch (6- to 7-dm) d.b.h. classes. Tree size classes and plant species data for *P. ponderosa* stands are shown in tables A–1 and A–3.

Pinus ponderosa/Festuca arizonica

Description.—The *Pinus ponderosa/Festuca arizonica* habitat type is represented by two stands. One is located on Blue Creek near McDonough Reservoir, and the other on Cochetopa Pass. The *P. ponderosa/F. arizonica* habitat type occurs on moderate to steep (12–31%) southeast- to east-facing slopes. Within the habitat type soils are deep, well-drained sandy loam (table 1).

This habitat type is recognized by the constant presence and limited reproductive success of open-grown *Pinus ponderosa*, and the abundance and dominance of *Festuca arizonica* (18–30% cover) in the undergrowth (fig. 5). *Pseudotsuga menziesii* and *Pinus aristata* are occa-

sional associates in the overstory. Shrubs are sparse; the most important are *Juniperus communis, Ribes cereum*, and *Ribes inerme*. In addition to *F. arizonica*, other important graminoids are *Carex geophila, Elymus elymoides, Koeleria macrantha, Muhlenbergia montana*, and *Oryzopsis hymenoides*. Forbs with highest cover include *Antennaria rosea, Artemisia frigida, Chaenactis douglasii, Erigeron glabellus, Geranium caespitosum, Hymenoxys richardsonii*, and *Potentilla hippiana*.

The *P. ponderosa/F. arizonica* habitat type has been reported throughout southern Colorado, on the Pike, Rio Grande, and San Juan National Forests (DeVelice et al. 1986, Radloff 1983). It also occurs in New Mexico and Arizona (Alexander et al. 1987, DeVelice et al. 1986, Fitzhugh et al. 1987, Hanks et al. 1983).

Management implications.—The potential for timber production in the *P. ponderosa/F. arizonica* habitat type is low to very low because of low stand density and poor site quality. *P. ponderosa* regeneration is patchy and irregular, occurring only in rare instances when favorable seed and climatic years coincide. Moreover, regeneration is not likely to be improved by seedbed preparation unless it is keyed to favorable environmental conditions and seed supply. Standard shelterwood and seed-tree even-aged cutting methods are appropriate for this habitat type. Group selection and group shelterwood mimic natural stand configurations. Individual tree selection is usually not appropriate because of the likelihood of sporadic reproduction which results in incomplete representation of age or size classes (Alexander 1986c).

Forage production for livestock is moderate to high, depending on range condition and grazing management. *F. arizonica* and *M. montana* are palatable to cattle, especially early in the season, but overgrazing may result in site degradation and reduced forage production. The grazing system should program rest every few years where establishment of *P. ponderosa* regeneration is critical. The habitat type has moderate potential for early winter or transitional range for big game. The *P. ponderosa/F. arizonica* habitat type has limited potential for increasing water yield but does provide watershed protection. The potential for developed and dispersed recreation is limited by the fragmented occurrence of *P. ponderosa*-dominated vegetation on the Gunnison National Forest.

Figure 5.—*Pinus ponderosa/Festuca arizonica* habitat type west of Cochetopa Pass. *F. arizonica, Muhlenbergia montana*, and *Hymenoxys richardsonii* are the principal undergrowth species.

Figure 6.—*Pinus ponderosa/Festuca idahoensis* habitat type along Alpine Road in Narrow Grade Creek. *Artemisia tridentata, Carex geophila, F. idahoensis*, and *Lupinus argenteus* are important undergrowth species.

Pinus ponderosa/Festuca idahoensis

Description.—The *Pinus ponderosa/Festuca idahoensis* habitat type occurs throughout the Gunnison Basin, but usually below the study area. This habitat type, originally classified as a *P. ponderosa/Artemisia tridentata* plant association by Komarkova,[3] was sampled on one plot on a gentle to moderate (11%) southerly slope, located along the Alpine Road in Narrow Grade Creek on that part of the Uncompahgre National Forest included in the study area. Within the habitat type, slopes usually are gentle and sites cool and dry. Soils are well drained and moderately deep loams (table 1).

This habitat type is recognized by the constant presence and limited reproductive success of *Pinus ponderosa*, with no other tree species present. The undergrowth in the stand sampled is dominated by *Artemisia tridentata* (65% cover) that increased because of past grazing use that also reduced the *Festuca idahoensis* cover (fig. 6). *Mahonia repens* is the only other important shrub. Major graminoids include *Carex geophila, F. idahoensis* (6% cover), and *Koeleria macrantha*. The forb layer contains a number of species, but only *Lupinus argenteus* has more than 1% cover.

The *P. ponderosa/F. idahoensis* habitat type has been described throughout the northern Great Basin, but the stand on the Gunnison National Forest is the southernmost known occurrence. This habitat type has been reported in eastern Washington (Daubenmire and Daubenmire 1968), Idaho (Cooper et al. 1987, Steele et al. 1981), central and southeastern Montana (Hansen and Hoffman 1987, Pfister et al. 1977), northern Utah (Mauk and Henderson 1984), and in the Bighorn Mountains of north-central Wyoming (Hoffman and Alexander 1976).

Management implications.—Timber productivity in the *P. ponderosa/F. idahoensis* habitat type is low and tree reproduction difficult to obtain after any kind of cutting (Alexander 1986c). Cutting should be directed toward improving visual appearance, recreation, or forage production. Stands can be harvested by removing the older, less vigorous, and diseased trees individually or in groups or patches. Forage production potential for livestock depends upon the amount of palatable graminoids in the undergrowth. This habitat type is considered poor range for deer (Dealy 1971); but this stand, with good representation of *Artemisia tridentata* in the undergrowth, has somewhat greater potential.

Partial cutting has the potential for increasing the shrub and herbaceous layers, thereby improving both forage production and diversity. However, this often is at the expense of the tree population. Burning tends to reduce *A. tridentata* and increase graminoids and forbs, thereby improving the forage value for cattle and elk at the expense of deer. This habitat type has no real potential for increasing water yields but does provide watershed protection. Potential sediment production can be relatively high.

PICEA PUNGENS SERIES

Picea pungens occurs throughout the Gunnison National Forest, but *P. pungens*-dominated stands are small and occur mainly in the southern part of the study area, either on rocky slopes in canyons at elevations ranging from 9,800 to 9,900 feet (2,987 to 3,017 m) or on riparian sites in valley bottoms at elevations of 6,700 to 7,900 feet (2,042 to 2,407 m) (table 1).

The *Picea pungens* series occurs as upland stands in the southwestern United States, where it is part of the "mixed conifers" (DeVelice et al. 1986, Moir and Ludwig 1979). The *P. pungens* series also occurs as riparian habitat types throughout the Rocky Mountains, usually in the montane zone (Johnston 1987).

The *P. pungens* series was sampled in four stands on the Gunnison National Forest representing two habitat types, one on dry, rocky upland slopes and one in riparian situations. Tree sizes on those plots where measurements were made ranged from seedlings to the ≥28-inch (≥7-dm) d.b.h. class. Tree size classes and plant species data for *P. pungens* stands are shown in tables A–1 and A–3.

Picea pungens/Festuca arizonica

Description.—The *Picea pungens/Festuca arizonica* habitat type is represented by two stands located in Cebolla Creek Canyon. This rocky habitat type was sampled on moderate (12–20%), warm, dry, south- to southeast-facing slopes. The rocks are of moderate size on slopes that are unstable. Soils are sandy loams (table 1).

The *P. pungens/F. arizonica* habitat type is recognized by very open, low-density stands of *Picea pungens* that contain seedlings, poles, and mature trees, indicating that *P. pungens* is perpetuating itself. Other tree species are absent or occasional. *Pinus ponderosa* may be seral on gentle, more stable, lower slopes, and *Pinus aristata* on steeper, less stable, upper slopes. The undergrowth is dominated by *Festuca arizonica* (18% cover) (fig. 7). The shrub layer is sparse, with *Ribes cereum* and *Rosa woodsii* having the highest cover. In addition to *F. arizonica*, important graminoids are *Carex geophila, Danthonia parryi, Elymus longifolius, Koeleria macrantha*, and *Muhlenbergia montana*. *D. parryi* is more conspicuous on gentle slopes where *P. ponderosa* reproduction is more evident. Forbs with the highest coverage are *Artemisia frigida, Geranium cespitosum, Heterotheca villosa, Mertensia lanceolata*, and *Selaginella densa*.

Figure 7.—*Picea pungens/Festuca arizonica* habitat type in Cebolla Creek Canyon. *Ribes cereum, Rosa woodsii, Danthonia parryi, Muhlenbergia montana*, and *Artemisia frigida* are important undergrowth associates.

The *P. pungens/F. arizonica* habitat type has been identified on the San Juan National Forest by DeVelice et al. (1986), but it has not been reported elsewhere in Colorado (Alexander 1987). This habitat type also occurs in northern New Mexico (DeVelice et al. 1986, Fitzhugh et al. 1987).

Management implications.—The potential for timber production in the *P. pungens/F. arizonica* habitat type is very low because of poor site quality and low tree density. Moreover, timber harvesting would risk initiating

mass soil movement. *F. arizonica*, *M. montana*, and especially *D. parryi* are highly palatable to cattle early in the grazing season. The relatively stable, gentle lower slopes with good representation of *D. parryi* have the highest forage potential in the habitat type. Care must be used in grazing this habitat type; overuse by livestock may also initiate erosion and subsequent mass soil movement. Big game may use this habitat type as transitory range. The *P. pungens/F. arizonica* habitat type has little value for increased water yields but does provide watershed protection if left undisturbed.

Picea pungens/Amelanchier alnifolia

Description.—The *Picea pungens/Amelanchier alnifolia* habitat type, represented by two plots, occupies a small acreage throughout the Rocky Mountains, but it is a highly conspicuous and important habitat type. It is common along stream channels classified as A or B in the montane zone throughout Colorado and Wyoming (Rosgen 1985). On the Gunnison National Forest, it occurs on steep (36–70%) northwest- to east-facing benches adjacent to streams, which occupy well-drained bottomlands, and on well-drained north-facing escarpments, especially around Cathedral. The stands sampled, located on Muddy Creek, Paonia District, and in Coal Creek Valley near the Paonia Reservoir, are typically small *P. pungens*-dominated vegetation growing on well-defined, relatively well-drained, and high gradient streamside benches, adjacent to less well-drained, lower gradient channels dominated by *Salix* spp. (Rosgen 1985). Soils are well-developed loams derived from fluvium and alluvium deposits (table 1).

The *P. pungens/A. alnifolia* habitat type is recognized by the dominance and reproductive success of *Picea pungens* in the overstory and the presence of *Amelanchier alnifolia* (6–8% cover) in the undergrowth (fig. 8). *Pseudotsuga menziesii*, *Pinus ponderosa*, and *Populus angustifolia* are the most common associates, although they are not well represented in the stands sampled. The shrub layer is well represented. Included are *A. alnifolia*, *Lonicera involucrata*, *Paxistima myrsinites*, *Prunus virginiana*, *Ribes inerme*, *Rosa woodsii*, *Salix* spp., *Swida sericea*, and *Symphoricarpos oreophilus*. Important graminoids include *Agrostis hyemalis*, *Bromus porteri*, *Calamagrostis canadensis*, *Carex* spp., *Elymus trachycaulus*, and *Festuca thurberi*. Forbs with the highest cover are *Achillea lanulosa*, *Antennaria rosea*, *Cirsium* spp., *Equisetum arvense*, *Fragaria virginiana*, *Geranium richardsonii*, *Geum rivale*, *Heracleum sphondylium*, *Osmorhiza depauperata*, *Rubeckia ampla*, *Senecio serra*, *Smilacina amplexicaulis*, *Smilacina stellata*, *Solidago multiradiata*, and *Viola vallicola*.

The *P. pungens/A. alnifolia* habitat type has been reported on the White River National Forest to the north of the Gunnison National Forest (Hess and Wasser[2]). Hoffman[5] identified a *P. pungens/Alnus incana* habitat type on the Grand Mesa and Uncompahgre National Forests to the west of the Gunnison National Forest that is similar to this habitat type. This habitat type also closely resembles the *P. pungens/Poa pratensis* and *P. pungens/Cornus stolonifera* (*P. pungens/S. sericea*) habitat types identified in northern New Mexico (Alexander et al. 1984, DeVelice et al. 1986, Fitzhugh et al. 1987, Moir and Ludwig 1979) and in western Wyoming (Youngblood et al. 1985). A plant community similar to this habitat type has been observed on the Routt National Forest in Colorado and on the Bighorn National Forest in north-central Wyoming.

Figure 8.—*Picea pungens/Amelanchier alnifolia* habitat type in Coal Creek Valley near Paonia Reservoir. *A. alnifolia*, *Ribes inerme*, *Rosa woodsii*, *Symphoricarpos oreophilus*, and *Swida sericea* dominate the undergrowth.

Management implications.—The primary value of this riparian, bottomland habitat type is for recreational use and as food and cover for wildlife. Many stands have roads through them because of their easy accessibility. Management activities, therefore, are highly visible. Timber production potential is relatively high, but the value for timber is low in relation to other resources. The first choice in this habitat type should be nonmanipulative management. Any timber harvesting should be light, using either shelterwood or selection cutting to open up the stand just enough to reduce the likelihood of associated species of more tolerant tall shrubs replacing *P. pungens*. The initial entry should remove the smaller trees, because cutting the large trees is likely to result in top breakage to the smaller trees. The potential for increasing forage production is high, especially where past use has decreased the amount of

Carex spp. and increased the more palatable graminoids. However, any timber harvesting or livestock use must be rigidly controlled because of the sensitivity of soils and landforms to disturbance. Because this habitat type naturally provides good all-season cover and palatable forage for elk, any cutting that increases forage production improves elk habitat, as long as adequate hiding cover is retained. The potential for increasing water yield is high, but management directed toward this objective (as well as other manipulative treatments) needs to be weighed against goals of the special prescription applied to riparian sites. Developed recreation must be carefully situated because of the sensitivity of soils to compaction and subsequent site degradation.

PSEUDOTSUGA MENZIESII SERIES

The *Pseudotsuga menziesii* series most often occurs on steep north-facing slopes with shallow soils, but also may be found on gentler east- and west-facing slopes with deep soils. *P. menziesii* grows in the montane zone on the Gunnison National Forest at elevations that range from 7,960 feet (2,426 m) to 9,920 feet (3,024 m). *P. menziesii* generally occupies cooler sites at the same elevations occupied by *Pinus ponderosa* (table 1). *P. menziesii* also commonly occurs as a seral species in stands dominated by other tree species in the montane zone.

The *P. menziesii* series was sampled in nine stands representing six habitat types. Tree sizes in measured stands range from seedlings to the ≥28-inch (≥7-dm) d.b.h. class. Tree size classes and plant species data for *P. menziesii* stands are given in tables A–1 and A–4.

Pseudotsuga menziesii/Paxistima myrsinites

Description.—The *Pseudotsuga menziesii/Paxistima myrsinites* habitat type is found at upper elevations within the series on the Gunnison National Forest. It was sampled in only one stand on a steep (58%), northwest-facing lower slope, south of Kebler Pass. Soils are a shallow, sandy loam (table 1). Within the habitat type, slopes are steep to very steep and rocky, with soils derived from sedimentary rock. The *P. menziesii/P. myrsinites* habitat type is one of the coolest within the series and often is found adjacent to the subalpine forest zone.

The *P. menziesii/P. myrsinites* habitat type is recognized by the presence and reproductive success of *Pseudotsuga menziesii*, and by the abundance and dominance of the low shrub *Paxistima myrsinites* (12% cover) in the undergrowth (fig. 9). Other important shrub species are *Amelanchier alnifolia, Holodiscus dumosus, Mahonia repens, Ribes inerme*, and *Symphoricarpos oreophilus*. Important graminoids are *Bromus pumpellianus, Carex geyeri, Festuca thurberi*, and *Poa leptocoma*. The most conspicuous forbs are *Helianthella quinquenervis, Heracleum sphondylium, Urtica gracilis*, and *Veratrum tenuipetalum*. The high cover of *V. tenuipetalum* in this stand may reflect heavy past grazing use despite the instability of site.

Figure 9.—*Pseudotsuga menziesii/Paxistima myrsinites* habitat type on a scree slope south of Kebler Pass. *P. myrsinites, Carex geyeri*, and *Urtica gracilis* dominate the undergrowth.

Hoffman and Alexander (1980, 1983) and Hess and Wasser[2] described this habitat type on the Routt and White River National Forests in Colorado, located north of the Gunnison National Forest. The *P. menziesii/P. myrsinites* habitat type has not been reported elsewhere in the Rocky Mountain or Intermountain regions by investigators using standard habitat type methodology, despite the fact that *Paxistima myrtinites* is well represented throughout these regions (Alexander 1985, 1988). It may be that its widespread distribution has caused many ecologists to reject *P. myrsinites* as an indicator species.

Management implications.—Information available on the management of the *P. menziesii/P. myrsinites* habitat type is limited. Timber productivity and livestock forage production are both low, because the habitat type occurs in dry, rocky situations. Clearcut openings may be especially difficult environments for successful *P. menziesii* regeneration because of limited moisture. Moreover, because of the steep slopes and instability associated with this habitat type, any timber harvesting or livestock grazing increases the risk of mass soil movement. Big game may browse the taller shrub species at times, and hiding cover usually is very good. The potential for increasing water yield is low because of instability, but the habitat type does provide watershed protection if undisturbed.

Pseudotsuga menziesii/Purshia tridentata

Description.—The *Pseudotsuga menziesii/Purshia tridentata* habitat type was sampled in two stands. One stand is on a moderate (21%) south-facing slope on Major Creek near the Old Monarch Pass road in the Sawatch Range, and the other is on a moderate (14%) southwest-facing slope below Black Sage Pass in the Sawatch Range. These stands were originally classified as *Pseudostuga menziesii/Arctostaphylos adenotricha* (stand 92) and *Pinus ponderosa/Artemisia tridentata* (stand 100) habitat types, respectively, by Komarkova.[3] Soils are loams (table 1). The *P. menziesii/P. tridentata* habitat type occurs elsewhere in the study area on gentle to moderate, rocky, dry slopes with relatively deep soils.

This habitat type is recognized by the dominance and reproductive success of *Pseudotsuga menziesii* in the overstory, and the abundance and dominance of the shrub *Purshia tridentata* (15–30% cover) in the undergrowth (fig. 10). *Pinus ponderosa, Pinus contorta,* and/or *Populus tremuloides* may be associated seral tree species, and any one of these may dominate the overstory in late seral stages. *Arctostaphylos adenotricha, Juniperus communis,* and *Mahonia repens* are important associated shrubs. In one stand (100), *Artemisia tridentata* has very high (60%) cover because of past grazing use. In stand 92, *A. adenotricha* has high cover (15%), but is not as good an indicator as *P. tridentata* (30% cover). Important herbaceous species include *Carex foenea, Carex geyeri, Koeleria macrantha, Antennaria rosea, Fragaria virginiana, Senecio* spp., and *Solidago multiradiata*.

Figure 10.—*Pseudotsuga menziesii/Purshia tridentata* **habitat type near Old Monarch Pass, Sawatch Range.** *Pinus contorta* **is a seral species in this stand.** *P. tridentata, Arctostaphylos adenotricha,* **and** *Carex geyeri* **dominate the undergrowth.**

The *P. menziesii/P. tridentata* habitat type has not been reported in Colorado (Alexander 1987) or elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988). However, it does have undergrowth similar to the *P. menziesii/Arctostaphylos uva-ursi* (*A. adenotricha*) habitat type described in southwestern New Mexico by Fitzhugh et al. (1987) and in Montana by Pfister et al. (1977); also, there is some evidence that the *P. menziesii/P. tridentata* plant community is seral to *P. menziesii/A. uva-ursi* habitat type in the northern Rockies. The *Pinus ponderosa/P. tridentata* habitat type on the Roosevelt National Forest in the Colorado Front Range (Hess and Alexander 1986) and in southern Utah (Youngblood and Mauk 1985) has undergrowth similar to the *P. menziesii/P. tridentata* habitat type on the Gunnison National Forest. This *P. ponderosa*-dominated "habitat type" may be a long-lived seral plant community that will ultimately be succeeded by the *P. menziesii/P. tridentata* plant association.

Management implications.—Timber productivity potential in the *P. menziesii/P. tridentata* habitat type is very low, and tree regeneration may be difficult to obtain, especially on disturbed soils which tend to be very dry. Forage production potential for livestock is low because of slow plant growth associated with thin, rocky soils and low precipitation. This habitat type has the potential to be good spring-fall range for mule deer, because *P. tridentata* is potentially very palatable to deer. Partial cutting increases the shrub and herbaceous layers, improving both diversity and forage production. Deer also use the habitat type for food and hiding cover in the summer, especially stands with good representation of *Artemisia tridentata*. Potential is low for increasing water yield, but stands do provide watershed protection.

Pseudotsuga menziesii/Symphoricarpos oreophilus

Description.—The *Pseudotsuga menziesii/Symphoricarpos oreophilus* habitat type is represented by two stands; one on the Lake Fork of the Gunnison River, the other in Spring Creek Canyon. These stands occur on moderate (21%) to very steep (70%) slopes. Aspect varies from west- to east-facing. Soils in the sampled stands are loams (table 1). The habitat type may occur on sedimentary soils, on steep, rocky slopes at lower elevations within the forested zone.

This is the most widespread *P. menziesii*-dominated habitat type on the Gunnison National Forest. It occurs on all but south aspects and generally on gentler slopes well below the subalpine zone. At lower elevations, the *P. menziesii/S. oreophilus* habitat type integrates with plant associations dominated by *Quercus gambelii* and/or *Amelanchier alnifolia*.

The *P. menziesii/S. oreophilus* habitat type is recognized by the overstory dominance and reproductive suc-

cess of *Pseudotsuga menziesii*. *Pinus flexilis* is an occasional overstory associate. The undergrowth is dominated by *Symphoricarpos oreophilus* (4–10% cover) (fig. 11). *Ribes inerme* and *Rosa woodsii* are the only other major shrubs. Important graminoids include *Carex geyeri*, *Elymus longifolius*, *Festuca idahoensis*, *Koeleria macrantha*, and *Poa nemoralis* ssp. *interior*. The forb layer is dominated by *Atragene columbiana*, *Artemisia frigida*, *Fragaria ovalis*, *Mertensia lanceolata*, *Selaginella densa*, *Solidago multiradiata*, and *Thalictrum fendleri*.

The *P. menziesii/S. oreophilus* habitat type has been reported in the White River National Forest to the north by Hess and Wasser;[2] it has also been described from the Piceance Basin in northwestern Colorado by Tiedeman (1978). A *P. menziesii/S. oreophilus* habitat type has been reported in southeastern Montana (Pfister et al. 1977), central Idaho (Steele et al. 1981), northwestern Wyoming (Steele et al. 1983), and in Utah (Mauk and Henderson 1984, Youngblood and Mauk 1985).

Management implications.—Timber productivity in this warm, dry habitat type is below average for *P. menziesii*. Regeneration is likely to be sporadic and difficult to obtain, especially if stands are clearcut, and they occur as small islands of trees. Sites tend to dry out rapidly because water loss from soil and vegetation is accelerated when the overstory is removed. Group selection, and group and uniform shelterwood cuttings approximate the regeneration patterns found in natural stands. Forage potential for livestock varies, depending on the abundance of palatable graminoids in the undergrowth; however, heavy grazing will remove these graminoids, with little chance that they will reestablish. Big game may use the *P. menziesii/S. oreophilus* habitat type for winter food and cover, especially where stands are adjacent to shrublands that also provide winter food. The potential for increasing water yield is low. The habitat type provides watershed protection, but erosion hazard is high and soil-loss tolerance low on steep slopes.

Figure 12.—*Pseudotsuga menziesii/Carex geyeri* habitat type, East Red Creek, West Elk Mountains. *Rosa woodsii* and *Symphoricarpos oreophilus* are the principal associates of *C. geyeri* in the undergrowth.

Figure 11.—*Pseudotsuga menziesii/Symphoricarpos oreophilus* habitat type in Spring Creek Canyon. *Pinus flexilis* is present in the overstory. *S. oreophilus*, *Rosa woodsii*, and *Festuca idahoensis* are important undergrowth species.

Pseudotsuga menziesii/Carex geyeri

Description.—The *Pseudotsuga menziesii/Carex geyeri* habitat type is represented by two stands on the Gunnison National Forest. One stand is in East Red Creek in the Elk Mountains, the other in Soap Creek Canyon. These stands are on gentle to moderate (11–21%) slopes, with aspects varying from northeast to southwest. Soils are relatively deep, well-drained, sandy loams (table 1). Within this habitat type, slopes usually are steep to very steep, with northerly aspects, and well-drained. Soils are derived from sedimentary rock.

This habitat type is recognized by the overstory dominance and reproductive success of *Pseudotsuga menziesii*. In some stands in this habitat type, *Pinus ponderosa* may be a seral codominant. *Picea pungens* and *Populus tremuloides* are occasional overstory associates. The undergrowth is dominated by *Carex geyeri* (35–60% cover) (fig. 12). Major shrub species include *Amelanchier alnifolia*, *Arctostaphylos adenotricha*, *Juniperus communis*, *Mahonia repens*, *Prunus virginiana*, *Purshia tridentata*, *Ribes inerme*, *Rosa woodsii*, and *Symphoricarpos oreophilus*. *S. oreophilus* has high cover (25%) in one stand (222), which may represent a phase of this habitat type comparable to the *P. menziesii/C. geyeri* habitat type, *S. oreophilus* phase reported from central Idaho by Steele

et al. (1981). However, this cannot be confirmed on the Gunnison National Forest without additional sampling. In addition to *C. geyeri*, important graminoids are *Bromus canadensis, Festuca arizonica, Koeleria macrantha*, and *Poa* spp. The forb layer is dominated by *Achillea lanulosa, Antennaria* spp., *Erigeron speciosus, Galium septentrionale, Lathyrus leucanthus*, and *Thalictrum fendleri*.

Hess and Alexander (1986) identified the *P. menziesii/C. geyeri* habitat type on the Arapaho National Forest. This habitat type has not been reported elsewhere in Colorado (Alexander 1987), but it is closely related to the *P. menziesii/S. oreophilus* habitat type in the study area and in the White River National Forest (Hess and Wasser[2]). Pfister et al. (1977) in Montana east of the Continental Divide, Cooper et al. (1987) in northern Idaho, and Steele et al. (1981) in central Idaho reported a *P. menziesii/C. geyeri* habitat type, but the plant species differ from the habitat type on the Gunnison National Forest.

Management implications.—The potential for timber production in the *P. menziesii/C. geyeri* habitat type is moderate to low. Moreover, this habitat type often occurs on steep slopes. If *P. menziesii* is harvested, cutting methods that maintain overstory shade and minimize soil disturbance are most appropriate for natural reproduction because sites are dry and become drier when opened up. Clearcutting may result in a significant increase in *C. geyeri* in the undergrowth, especially if disturbance during logging is not severe. However, regeneration of *P. menziesii* is likely to be difficult to obtain with any cutting method, especially where there is pressure from big game and/or precipitation is below average. The potential for forage production for livestock is moderate, and moderate to high for big game on or near winter range. This habitat is valuable to big game mostly as hiding and thermal cover. Heavy livestock or big game use, or heavy mechanical seedbed preparation may deplete the *C. geyeri* sod, increase erosion and sedimentation potentials, and facilitate invasion by *Artemisia* spp. The potential for increasing water yield is lower than in subalpine forests.

Pseudotsuga menziesii/Festuca idahoensis

Description.—The *Pseudotsuga menziesii/Festuca idahoensis* habitat type was sampled in only one stand on a moderate (14%) east-facing slope along the Cold Spring Road, near Upper Dome Reservoir. Soils are a deep, sandy loam (table 1). Stands in this habitat type are typically patchy, with a more open canopy than other *Pseudotsuga*-dominated habitat types. They often are heavily grazed.

The *P. menziesii/F. idahoensis* habitat type is recognized by the dominance and reproductive success of open-grown *Pseudotsuga menziesii*, and the abundance and dominance of *Festuca idahoensis* (40% cover) in the undergrowth (fig. 13). Occasionally, *Pinus ponderosa* occurs in the overstory. Shrubs are sparse with only *Juniperus communis* and *Ribes cereum* present. In addition to *F. idahoensis*, other important graminoids include

Figure 13.—*Pseudotsuga menziesii/Festuca idahoensis* habitat type, Cold Springs, Upper Dome Reservoir. Condition of *P. menziesii* reflects difficult site. *F. idahoensis* and *Koeleria macrantha* dominate the undergrowth.

Carex geyeri and *Koeleria macrantha*. *Arabis drummondii* and *Descurainia richardsonii* are the major forbs in the sampled stand.

The *P. menziesii/F. idahoensis* habitat type has not been reported elsewhere in Colorado (Alexander 1987). This habitat type has been reported in southwestern Montana (Pfister et al. 1977), and northern and central Idaho (Cooper et al. 1987, Steele et al. 1981). However, the composition of the undergrowth in this northern *P. menziesii/F. idahoensis* habitat type is considerably different from the habitat type described here.

Management implications.—Timber productivity in the *P. menziesii/F. idahoensis* habitat type is low because of poor tree growth and low stand density. Establishment of regeneration following any cutting method is likely to be slow because both seed supply and available soil moisture are limited. While partial cutting will tend to increase graminoids in the undergrowth, clearcutting generally will result in conversion to grassland, with very slow reinvasion of *P. menziesii*. Removal of individual trees in a light sanitation-salvage cutting will permit timber harvest and still protect the site. Since this habitat type occurs on gentle to moderate slopes, it is compatible with livestock grazing. The potential for forage production for livestock, primarily cattle, is moderate, but may improve where removal of the overstory increases the representation of *F. idahoensis* in the undergrowth. Although the potential for big-game browse production is low, deer and elk may use the *P. menziesii/F. idahoensis* habitat type both for early and late season forage and cover. The potential for water yield improvement is low, but the habitat type provides watershed protection.

Pseudotsuga menziesii/Jamesia americana

Description.—The *Pseudotsuga menziesii/Jamesia americana* habitat type has some of the oldest *P. menziesii* encountered on the Gunnison National Forest. It was sampled in only one stand, located on a moderate (21%) south-facing slope on the west side of Monarch

Pass near Sargents. Soils are a shallow, coarse loam derived from igneous or metamorphic rock (table 1). Within the habitat type, sites have steep slopes with large boulders. The stands in which the sample plot was located are the first evidence of the occurrence of the *P. menziesii/J. americana* habitat type west of the Continental Divide.

This habitat type is recognized by the overstory dominance and reproductive success of *Pseudotsuga menziesii*, and the conspicuous presence of *Jamesia americana* (7% cover) in the undergrowth (fig. 14). *Pinus ponderosa* may be a seral overstory associate, and *Juniperus scopulorum* also may be present. Major shrub associates of *J. americana* include *Arctostaphylos adenotricha*, *Mahonia repens*, and *Rosa woodsii*. On the eastern slope of the Continental Divide, there usually is a greater variety of medium to tall shrubs present. The herbaceous layer is dominated by *Carex brevipes*, *Poa pratensis*, *Apocynum androsaemifolium*, *Senecio fendleri*, and *Solidago multiradiata*.

The *P. menziesii/J. americana* habitat type was reported on the Roosevelt National Forest by Hess and Alexander (1986) and on the Pike National Forest by Radloff (1983). It has not been reported elsewhere in the Rocky Mountain or Intermountain regions by investigators using standard habitat type methodology (Alexander 1985, 1988).

Figure 14.—*Pseudotsuga menziesii/Jamesia americana* habitat type near Monarch Ridge, Sawatch Range. *Pinus contorta* is a seral overstory species. *J. americana*, *Arctostaphylos adenotricha*, and *Mahonia repens* have high coverage in the undergrowth.

Management implications.—Although this habitat type occurs in a moister environment than some other *P. menziesii*-dominated habitat types, the potential for timber production is low because of low site quality associated with shallow, rocky soils. Moreover, steep slopes and surface roughness generally preclude any harvesting of stands in the *P. menziesii/J. americana* habitat type with conventional methods. The potential for forage production for livestock is low. The sampled stand showed little evidence of grazing. There is moderate potential for big game on winter range as hiding and thermal cover; the shrubs generally are not browsed. The potential for increasing streamflow is low because of the difficulty in harvesting stands and low precipitation. This habitat type does provide watershed protection, however.

POPULUS ANGUSTIFOLIA SERIES

Populus angustifolia is a deciduous forest tree species of the upper foothills and lower montane zones in the Gunnison Basin. It dominates rocky riparian areas, such as narrow benches of small streams and in the floodplains of larger streams, at elevations of 6,500 to 7,800 feet (1,981 to 2,377 m) (table 1). This series is represented by one stand and one habitat type located at 7,170 feet elevation (3,048 m). Tree size data are not available for this series. Plant species data for the *P. angustifolia* stand are shown in table A–5.

Populus angustifolia/Alnus incana-Swida sericea

Description.—The *Populus angustifolia/Alnus incana-Swida sericea* habitat type generally occurs on level to near level terrain that is subject to spring flooding and has a constantly high water table. The sampled stand is on Smith Fork, Paonia District. Soils are sandy loams. They are alluvium and colluvium, derived from parent materials of mixed geologic origin (table 1).

The *P. angustifolia/A. incana-S. sericea* habitat type is characterized by an overstory dominated by *Populus angustifolia*, with *Salix amygdaloides* as a codominant, and an undergrowth dominated by the shrubs *Alnus incana* and *Swida sericea* (10–55% cover). Other shrub species with high cover include *Acer glabrum*, *Prunus virginiana*, *Rosa woodsii*, *Salix exigua*, *S. ligulifolia*, *S. lutea*, and *Sambucus racemosa*. Major herbaceous species are *Dactylis glomerata*, *Elymus trachycaulus*, *Poa plaustris*, *Heracleum sphondylium*, *Hippochaete hyemalis*, *Smilacina stellata*, and *Solidago* spp. (fig. 15).

Although the sampled stand was not heavily grazed, this habitat type historically has been heavily utilized for grazing livestock and big game, and for recreation. Heavy use has resulted in significant vegetational changes on many sites in this habitat type, resulting in a stable undergrowth composed of introduced species, such as *Poa pratensis*, *Bromus inermis*, *Dactylis glomer-*

ata, and *Taraxacum officinale*. In these circumstances, the existing vegetation may be termed a zootic climax.

A closely related *P. angustifolia/Salix exigua* habitat type, with similar characteristics, has been reported in the Front Range on the Roosevelt National Forest by Hess and Alexander (1986), and in eastern Idaho by Youngblood et al. (1985). This habitat type also appears to be closely related to the *P. angustifolia/Amelanchier alnifolia* habitat type described by Hess and Wasser[2] on the White River National Forest. Although the *P. angustifolia/A. incana-S. sericea* habitat type has not been reported elsewhere in the Rocky Mountain and Intermountain regions, it is probably widespread throughout western Colorado, Utah, and western Wyoming.

Management implications.—Timber production is moderate, but *P. angustifolia* and *Salix amygdaloides*, which make up most of the volume in this habitat type, are not commercial forest tree species. Forage and browse production potential for livestock and big game may be high, but heavy grazing will decrease herbaceous production and *P. angustifolia* regeneration. Grazing and browsing reduce shrubs and increase the proportion of graminoids, which, with the exception of *Poa* spp., have low palatability. Diversified recreation use and road-building often are heavy because of close proximity to water, and these activities frequently have resulted in site degradation. This habitat type also provides cover for big game, and food and cover for a wide variety of non-game wildlife.

Figure 15.—*Populus angustifolia/Alnus incana-Swida sericea* habitat type, Smith Fork, Paonia District. *Salix* spp., *Acer glabrum, Alnus incana, Rosa woodsii, Hippochaete hyemalis*, and *Swida sericea* have high coverage in the undergrowth.

POPULUS TREMULOIDES SERIES

The *Populus tremuloides* series occurs throughout the montane and subalpine forest zones on the Gunnison National Forest. It also occurs on part of the Uncompahgre National Forest. The *P. tremuloides* series occupies a wide range of mesic environments on sites where high available moisture, coupled with favorable topographic positions, favors retention of soil moisture. This series occurs at elevations of 8,040 to 10,450 feet (2,450 to 3,185 m) (table 1).

There has been considerable discussion regarding the role of *P. tremuloides* as a climax and/or seral species in the Rocky Mountain and Intermountain regions; both assessments may be correct (Mueggler 1985a). In some areas, *P. tremuloides* dominates sites where fires apparently have destroyed coniferous forests. In time, on some of these sites, conifers gradually replace *P. tremuloides*. In other situations, conifer invasion is virtually nonexistent, even where fires occurred many years ago. Succession to coniferous forests apparently is slowed significantly by changes in soil properties resulting from site occupancy by the deciduous *P. tremuloides*. In other areas, *P. tremuloides* forests appear to be climax without evidence of conifer invasion. According to Mueggler (1976), complete conversion of *Populus* stands to coniferous climax forest on some sites may require more than a thousand fire-free years. The origin of both seral and climax *P. tremuloides*-dominated forests may be the same—destruction of coniferous forest by repeated fires.

P. tremuloides may more commonly be climax in western Colorado, where it occurs in large, apparently stable stands. Here, *P. tremuloides* tends to form stands on less stable sites with deeper, loamier soils that are less well drained compared to adjacent stands dominated by conifers. Part of *P. tremuloides*' success on a given site is its ability to develop loamy soils that are more favorable to the perpetuation of *Populus* than invasion and replacement by conifers. The latter tend to become established as climax species on shallower, coarse-textured, well-drained soils.

Many *P. tremuloides* forests are even-aged (or even-sized) (Jones and DeByle 1985); the trees originate from sprouts that occur shortly after a disturbance. In stands where older trees die naturally over a short time span, an even-aged replacement stand also may develop (Mueggler 1985a). Other stands are uneven-aged or multisized, and sprouts apparently provide enough young trees to perpetuate the species indefinitely. Two-storied stands also are relatively common and can develop when surface fires burn quickly through mature stands without killing all trees, thereby stimulating sprouting.

The *P. tremuloides* series was sampled in 13 stands representing seven habitat types. Tree sizes for those stands where measurements are available ranged from

seedlings to the 20- to 24-inch (5- to 6-dm) d.b.h. class. Tree populations and plant species data for the *P. tremuloides* stands are shown in tables A–1 and A–5.

Populus tremuloides/Arctostaphylos adenotricha

Description.—The *Populus tremuloides/Arctostaphylos adenotricha* habitat type was sampled in only one stand in the subalpine forest zone. The sampled stand is on an unstable, rocky slope near Middle Quartz Creek on a steep (40%) south-facing aspect. Soils are a coarse loam (table 1). *P. tremuloides* is represented by all age classes, including some very large trees.

This habitat type is recognized by the overstory dominance and reproductive success of *Populus tremuloides*. Other tree species are absent. Undergrowth cover is sparse (fig. 16). The most abundant shrubs are *Arctostaphylos adenotricha, Ribes inerme, Shepherdia canadensis,* and *Symphoricarpos oreophilus*. Herbaceous species with significant cover are *Bromus porteri, Carex geophila,* and *Poa nemoralis* ssp. *interior*.

Powell[7] reported a *P. tremuloides/A. adenotricha* community type on the Pike and San Isabel National Forests, but the composition of the undergrowth is different. The *P. tremuloides/A. adenotricha* habitat type has not been reported elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988). The combination of *P. tremuloides* and *A. adenotricha*, a tree species with relatively high moisture requirements and a low shrub that normally indicates a dry soil, is unusual and suspicious. Successional relationships to *Pinus contorta/Arctostaphylos uva-ursi* (*A. adenotricha*) (Hoffman and Alexander 1976, Mauk and Henderson 1984, Radloff 1983) are suspected because of excessive soil drainage here and floristic similarities. Additional sampling is needed to confirm this relationship on the Gunnison National Forest.

[7] *Powell, David C. Aspen community types of the Pike and San Isabel National Forests in south-central Colorado. (Manuscript in preparation.)*

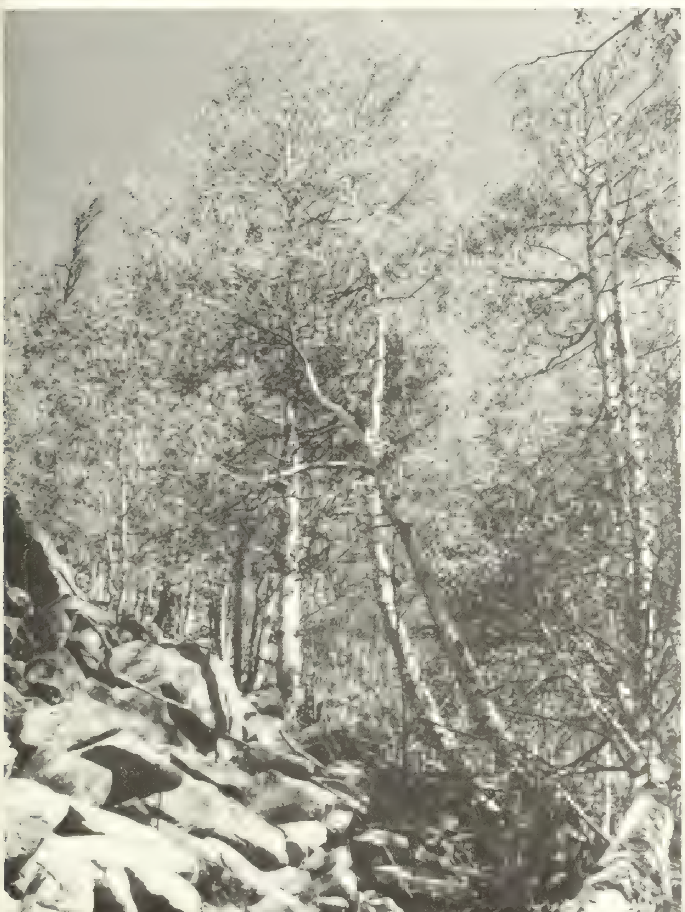

Figure 16.—*Populus tremuloides/Arctostaphylos adenotricha* habitat type near Alpine Tunnel, Sawatch Range. Undergrowth is sparse.

Management implications.—The potential for timber production in the *P. tremuloides/A. adenotricha* habitat type is moderate to low. However, because of the instability of the site, any timber harvesting is likely to increase the risk of mass soil movement. Stands in this habitat type have low probability of being successfully burned, because medium-height shrubs are uncommon, and herbaceous fuels are seldom dense enough to carry a fire. Any successful burning probably would require fuels created by cutting.

The potential for forage production is low to moderate, but the sites are too unstable for livestock grazing. Big game may use this habitat type as transitional range, and the undergrowth has moderate to high big game forage suitability. Big game browsing may damage *P. tremuloides* sprouts. Although the habitat type occurs in relatively high precipitation zones, there is little opportunity to increase streamflow, because sites are very well drained and opportunities to harvest timber are limited by instability. Visual contrast is low because of the absence of conifers, and the low density of shrubs does not provide much texture or variety in seasonal color in the foreground.

Populus tremuloides/Festuca arizonica

Description.—The *Populus tremuloides/Festuca arizonica* habitat type was sampled in only one stand in the lower subalpine zone, along the Mexican Joe Gulch road. This isolated stand, located on an unstable, rocky slope, showed no evidence of replacement of *P. tremuloides* by conifers. Soils on this gentle to moderate (11%) east-facing aspect are sandy loams (table 1).

This habitat type is recognized by the overstory dominance and reproductive success of open-grown *Populus tremuloides*. Other tree species are absent. The undergrowth is dominated by *Festuca arizonica* (28% cover) (fig. 17). The shrub layer is sparse. In addition to *F. arizonica*, important graminoids are *Carex geyeri, Festuca thurberi,* and *Muhlenbergia montana*. Important forbs include *Achillea lanulosa, Lupinus argenteus, Oxytropis deflexa,* and *Senecio* spp.

The *P. tremuloides/F. arizonica* habitat type has not been identified elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988). It appears closely related to the *P. tremuloides/Festuca thurberi*

habitat type; but it occurs on warmer sites with thinner soils or outside the range of *F. thurberi*.

Management implications.—The potential for timber production in the *P. tremuloides/F. arizonica* habitat type is low, despite the relatively good growth of *P. tremuloides*, because the instability of the site limits timber harvesting. Moreover, since most stands in this habitat type are small and occur in meadows, timber harvesting may eliminate *P. tremuloides*. *F. arizonica*, *F. thurberi*, and *M. montana* are highly palatable to cattle, especially early in the grazing season; but despite the potentially high value for forage production, soil conditions are too unstable to risk grazing by livestock. Big game, especially elk, may use this habitat type as transitional range. The *P. tremuloides/F. arizonica* habitat type has little potential for increased water yields but does provide watershed protection. Visual contrast in the foreground is low because of the absence of conifers and shrub species.

Populus tremuloides/Festuca thurberi

Description.—*Populus tremuloides/Festuca thurberi* habitat type was sampled in three stands. One stand (233), near Beaver Creek on a gentle southeast-facing slope, initially was described as a *P. tremuloides/Lathyrus leucanthus* community type successional to *Pinus contorta* (Komarkova[3]). This assumption was based on the occurrence of *P. contorta* seedlings near the sampled area. The remaining two stands are north of Mill Creek in northeast Hillsdale County on gentle east-facing slopes. These were originally described as *Populus tremuloides/Festuca thurberi* and *P. tremuloides/Danthonia intermedia* community types successional to *Abies lasiocarpa* and *Picea engelmannii* (Komarkova[3]), based on the occurrence of a few scattered *P. engelmannii* seedlings in the stands but with no clear evidence that *P. tremuloides* is seral. Without documented evidence of replacement of *P. tremuloides* by conifers within the stands sampled, they tentatively are classified as a *P. tremuloides/F. thurberi* habitat type. Additional sampling is necessary to confirm this habitat type in the study area. Soils in the sampled stands are sandy loams (table 1).

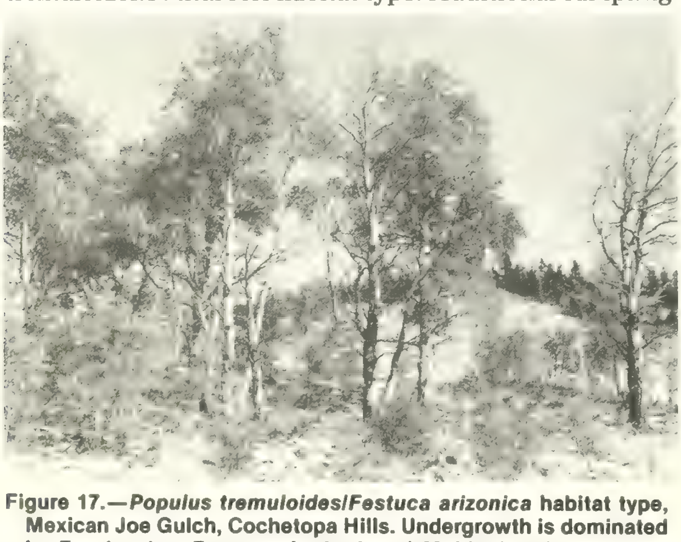

Figure 17.—*Populus tremuloides/Festuca arizonica* habitat type, Mexican Joe Gulch, Cochetopa Hills. Undergrowth is dominated by *F. arizonica*, *Festuca thurberi*, and *Muhlenbergia montana*.

Figure 18.—*Populus tremuloides/Festuca thurberi* habitat type near Beaver Creek. *F. thurberi*, *Arctostaphylos adenotricha*, *Carex geyeri*, *Arnica cordifolia*, and *Lathyrus leucanthus* are important undergrowth species.

The habitat type is recognized by the overstory dominance and reproductive success of *Populus tremuloides*. *P. tremuloides* is generally young in the stands sampled, and the only conifer associates present are a few scattered *Picea engelmannii* seedlings in stand 173. The undergrowth is recognized by the abundance of the graminoid *Festuca thurberi* (10–65% cover) (fig. 18). Major shrubs are *Arctostaphylos adenotricha* and *Rosa woodsii*. Other important graminoids include *Bromus carinatus*, *Carex geyeri*, *Danthonia intermedia*, *Elymus trachycaulus*, and *Festuca idahoensis*. Forbs with significant cover are *Achillea lanulosa*, *Arnica cordifolia*, *Erigeron speciosus*, *Fragaria virginiana*, *Lathyrus leucanthus*, *Solidago* spp., and *Thalictrum fendleri*. The high cover of *L. leucanthus* in stand 233 indicates considerable past grazing pressure reduced cover by more palatable herbaceous plants.

The *P. tremuloides/F. thurberi* habitat type has been described on the Arapaho, Roosevelt, and White River National Forests in Colorado by Hess and Alexander (1986), Hess and Wasser,[2] and Johnston and Hendzel.[8] Powell[7] described a *P. tremuloides/F. thurberi* community type on the Pike and San Isabel National Forests. Mueggler[9] described a *P. tremuloides/F. thurberi* community type in southern Utah that probably is successional to *Abies lasiocarpa*. It has not been reported elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988). *P. tremuloides/F. thurberi* stands are often adjacent to and related to *F. thurberi* grasslands, and the possibility exists that the small and marginal stands in this habitat type developed through expansion into the grasslands by *P. tremuloides* clones.

[8]*Johnston, Barry C., and Leonard Hendzel. 1985. Examples of aspen treatment, succession, and management of western Colorado. (Report) Rocky Mountain Region, Denver, Colo.*

[9]*Mueggler, Walter F. Aspen community types in the Intermountain region. (Manuscript in preparation. Supersedes Mueggler and Campbell 1982, 1986; Youngblood and Mueggler 1981.)*

Management implications.—Timber productivity in the dry *P. tremuloides/F. thurberi* habitat type is moderate to low. Clearcutting usually is an effective way to regenerate a new *P. tremuloides* stand. However, it is somewhat risky in this habitat type, because stands often are small and adjacent to *F. thurberi* grasslands, and there is a good chance of converting these stands to *F. thurberi* when the *P. tremuloides* overstory is removed. However, if the objective is enhancement of the grasslands, clearcutting should be beneficial. Success in regenerating stands in this habitat type is enhanced by burning immediately after clearcutting to reduce competition from undergrowth species. The potential for forage production is high on sites in good condition with a high cover of *F. thurberi* and associated graminoids. Forage is more palatable to cattle than sheep, but these stands usually are not very important rangelands, because they are small and *F. thurberi* is only moderately palatable in late spring-early summer. This habitat type can be heavily used by big game in the late fall and winter for food and cover. Heavy winter use by big game animals can damage mature *P. tremuloides* stems and can eliminate all sprouts. The potential for increasing streamflow is unknown. Erosion, sedimentation, and mass movement potentials are low. The *P. tremuloides/F. thurberi* habitat type usually has low visual potential in the foreground. Color contrast is low because of the absence of conifers, and the low density of shrubs does not provide much texture or variety in seasonal color. However, isolated stands in grasslands or shrublands can be locally important where the interstand contrast is visible. The potential is moderate for dispersed recreation, but it is low for developed recreation because of the isolated character of the stands and the susceptibility of *P. tremuloides* to disease resulting from injury and soil compaction.

Populus tremuloides/Symphoricarpos oreophilus

Description.—The *Populus tremuloides/Symphoricarpos oreophilus* habitat type was sampled in three stands on the Gunnison National Forest. One stand is in Smith Fork, Paonia District, on a gentle (7%) northeast-facing slope; the second stand is south of McClure Pass on a gentle (5%) east- to northeast-facing slope; and the third stand is in Buckhorn Gulch, near Black Mesa, on a moderate (14%) west-facing slope. Within the habitat type, sites are on protected benches and slopes, usually on gentle slopes and relatively stable sites. Stands are typically patchy, with grassy openings within the *P. tremuloides* matrix. Soils are relatively deep, sandy loams, but are moderately well drained (table 1).

The *P. tremuloides/S. oreophilus* habitat type is recognized by the consistent presence and reproductive success of *Populus tremuloides*, and the abundance and dominance of *Symphoricarpos oreophilus* (10–65% cover) in the undergrowth (fig. 19). This habitat type occurs near the lower edge of the *Populus* zone on the Forest and is one of the warmest *P. tremuloides*-dominated habitat types. As sites become still drier, *P. tremuloides* is replaced by *Quercus gambelii*- or *Artemisia tridentata*-dominated vegetation. If replaced by *Q. gambelii*, it may form the *Q. gambelii/S. oreophilus* habitat type.

Figure 19.—*Populus tremuloides/Symphoricarpos oreophilus* habitat type in Smith Creek, Paonia District. *S. oreophilus, Carex* spp., *Achillea lanulosa*, and *Thalictrum fendleri* are principal undergrowth species.

In addition to *S. oreophilus*, important shrubs are *Amelanchier alnifolia, Mahonia repens, Prunus virginiana*, and *Rosa woodsii*. In one stand (188), the cover of *M. repens* is very high (70%), and Komarkova[3] originally classified this plot as a *P. tremuloides/M. repens* habitat type. However, since a *P. tremuloides/M. repens* habitat type has not been previously identified in Colorado (Alexander 1987), it is more likely a *M. repens* phase of the *P. tremuloides/S. oreophilus* habitat type. Additional sampling will be required to determine the status of *M. repens* in *P. tremuloides* stands in the study area.

The most important graminoids in this habitat type are *Bromus* spp., *Carex geyeri, Carex hoodii*, and *Elymus trachycaulus*. The rich forb layer is dominated by *Achillea lanulosa, Aquilegia coerulea, Conioselinum scopulorum, Erigeron glabellus, Fragaria virginiana, Galium septentrionale, Geranium richardsonii, Osmorhiza depauperata, Rudbeckia ampla, Senecio bigelovii, Thalictrum fendleri*, and *Viola canadensis*.

Hoffman and Alexander (1980, 1983), Hess and Wasser,[2] Hoffman,[5] and Johnston and Hendzel[8] identified this habitat type on the Grand Mesa, Routt, White River, Uncompahgre, and San Juan National Forests in

Colorado. Powell[7] described a *P. tremuloides/S. oreophilus* community type on the Pike and San Isabel National Forests. Tiedeman (1978) also described it in the Piceance Basin of northwestern Colorado. In the Medicine Bow National Forest and in the Bighorn Mountains, there are no undergrowth unions under *P. tremuloides* dominated by *Symphoricarpos* (Alexander et al. 1986, Hoffman and Alexander 1976). In western Wyoming, northern Utah, eastern Nevada, and central and southeastern Idaho, Mauk and Henderson (1984), Mueggler,[9] and Steele et al. (1981) identified *P. tremuloides/S. oreophilus*-dominated vegetation with similar associated undergrowth. Mueggler[9] described this vegetation as a community type, but indicated that *P. tremuloides/S. oreophilus* community types probably were stable and very likely valid habitat types.

Management implications.—This is the most common *Populus*-dominated habitat type on the Gunnison National Forest. Timber productivity is low to moderate in this mesic habitat type, depending on geographic location. While stands in the *P. tremuloides/S. oreophilus* habitat type may be self-regenerating, clearcutting usually is the preferred way to regenerate a new stand. This habitat type has the highest potential of any *P. tremuloides* habitat type for successful prescribed burning because of the combination of medium shrub and herbaceous fuels.

Annual precipitation is at least 18 inches (46 cm), with about 9 inches (23 cm) of runoff. Potential for increasing streamflow under management is unknown. This habitat type is spring and fall big game range, and use may be heavy. In years of low snowfall, it may be used all winter. Browse production is moderate because *S. oreophilus* is moderately palatable to big game. The habitat type is summer range for livestock. The potential is high for sheep and moderate for cattle. Under proper grazing management, herbage production may be as high as 800 to 1,000 pounds per acre (900 to 1,120 kg/ha). This habitat type has fairly good scenic quality, but generally less favorable foreground color contrast than mixed *Populus*-conifer stands. Mature and open stands generally are more visually attractive, with the shrub understory providing both texture diversity and variety in seasonal color. The potential for developed recreation is low because of the susceptibility of *P. tremuloides* to disease and subsequent death from injury and soil compaction. Slumping may be common, especially where slopes are steeper; these should be avoided in planning roads and trails.

Populus tremuloides/ Amelanchier alnifolia-Prunus virginiana

Description.—The *Populus tremuloides/Amelanchier alnifolia-Prunus virginiana* habitat type was sampled in two stands. One stand is in Smith Fork, on the Paonia District, on a moderate (21%) west-facing slope. The other stand is south of McClure Pass on a moderate (21%) southeast-facing slope. Soils are relatively deep, sandy loams (table 1).

Figure 20.—*Populus tremuloides/Amelanchier alnifolia-Prunus virginiana* habitat type west of McClure Pass. *A. alnifolia, P. virginiana, Rosa woodsii, Symphoricarpos oreophilus*, and *Thalictrum fendleri* dominate the undergrowth.

The *P. tremuloides/A. alnifolia-P. virginiana* habitat type is recognized by overstory dominance and reproductive success of *Populus tremuloides*, and the near absence of conifer species. The undergrowth is dominated by tall shrubs, either *Amelanchier alnifolia* (0–30% cover) and/or *Prunus virginiana* (4–45% cover), often approaching *P. tremuloides* in height (fig. 20). On the Gunnison National Forest, this habitat type is usually limited to protected lower slopes and valley bottoms on the Paonia District. The habitat type usually occurs near the lower limits of the *Populus* zone, and often is adjacent to *Quercus*- or *Amelanchier*-dominated woodlands and shrublands.

The undergrowth is a rich, multilayered mixture of tall shrubs, low- to medium-height shrubs, and herbaceous vegetation. Major tall shrubs are *Acer glabrum, Amelanchier alnifolia*, and *Prunus virginiana*. Low to medium shrubs are *Paxistima myrsinites, Ribes inerme, Rosa woodsii, Rubus parviflorus, Salix scouleriana*, and *Symphoricarpos oreophilus*. Important herbaceous species include *Bromus* spp., *Carex hoodii, Elymus trachycaulus, Achillea lanulosa, Delphinium nuttallianum, Fragaria virginiana, Galium triflorum, Geranium richardsonii, Heracleum sphondylium, Osmorhiza depauperata,*

Solidago spp., *Smilacina stellata, Streptopus fassettii*, and *Thalictrum fendleri*.

This habitat type has been reported on the San Juan National Forest by Johnston and Hendzel.[8] Powell[7] reported a *P. tremuloides/A. alnifolia* community type on the Pike and San Isabel National Forests. Mueggler[9] identified a number of *P. tremuloides/A. alnifolia*-dominated community types in southeastern Idaho, northwestern Wyoming, northern Utah, and eastern Nevada in which the associated undergrowth is similar to the *P. tremuloides/A. alnifolia-P. virginiana* habitat type reported here. Some of these community types probably are stable and, therefore, represent habitat types. This habitat type also has some similarity to the *P. tremuloides/Symphoricarpos oreophilus* habitat type described by Hess and Wasser[2] and Hoffman and Alexander (1980, 1983) on the Routt and White River National Forests; but, it is distinguished by the conspicuous presence of tall shrubs, such as *A. alnifolia, P. virginiana*, and sometimes *Acer glabrum* and *Quercus gambelii*.

Management implications.—Timber productivity in the *P. tremuloides/A. alnifolia-P. virginiana* habitat type is low to moderate; stem form is often crooked and stands often grow on steep slopes. Clearcutting usually is the preferred timber harvesting option to regenerate stands and usually is very successful. The potential for increasing streamflow under management is unknown. Forage production for livestock is highly variable but this habitat type can be fairly productive, especially for sheep [average 1,000 pounds per acre (1,120 kg/ha)], where the undergrowth consists of palatable forage plants. Heavy grazing, especially by sheep, may reduce the vigor and abundance of the tall shrubs. This habitat type generally provides good to excellent big game habitat because of the great amount of structural diversity contributed by the tall and low shrub layers, and the presence of quantities of good browse. Where stands in this habitat type are adjacent to critical big game winter range, the value is increased. The *P. tremuloides/A. alnifolia-P. virginiana* habitat type has fairly good foreground scenic quality, especially where there is considerable *Acer glabrum* in the undergrowth. Moreover, in addition to providing a variety in seasonal color, the multilayerd shrub understory provides texture diversity. Edges interfingered with shrubland may provide color contrast and enhance deer, elk, and antelope hiding cover. The potential for dispersed recreation is moderate, but the potential for developed recreation is low because of the susceptibility of *P. tremuloides* to disease and subsequent death from injury and soil compaction.

Populus tremuloides/Pteridium aquilinum

Description.—The *Populus tremuloides/Pteridium aquilinum* habitat type has limited distribution, and occurs in small stands on the Gunnison National Forest. It was sampled in two stands: one in Smith Fork, Paonia District, on a gentle (3%), sheltered, east-facing slope; the other south of McClure Pass on a moderate (11%) south-facing slope. Soils associated with this habitat type are deep and loamy (table 1).

Figure 21.—*Populus tremuloides/Pteridium aquilinum* habitat type west of McClure Pass. A variety of shrubs, graminoids, and forbs are associated with *P. aquilinum* in the undergrowth.

Populus tremuloides is the only tree species in these stands, and it is perpetuating itself. The undergrowth is dominated by *Pteridium aquilinum* (40–65% cover) (fig. 21). *P. aquilinum*, like *P. tremuloides*, establishes readily after fire, and cured, late-season vegetation can help carry a fire. Major shrub associates are *Amelanchier alnifolia, Prunus virginiana, Ribes inerme*, and *Symphoricarpos oreophilus*. Important graminoids are *Bromus pumpellianus, Carex geyeri, Elymus longifolius, Elymus trachycaulus*, and *Poa fendleriana*. There is a large variety of forbs; in addition to *Pteridium aquilinum*, forbs with high cover are *Achillea lanulosa, Cirsium* spp., *Delphinium nuttallianum, Dipsacus sylvestris, Erigeron* spp., *Galium septentrionale, Geranium richardsonii, Lathyrus leucanthus, Osmorhiza depauperta, Polemonium pulcherrimum, Thalictrum fendleri*, and *Viola canadensis*.

The *P. tremuloides/P. aquilinum* habitat type has been identified in Colorado on the Routt National Forest where it was confined to poorly drained areas, and on the Grand Mesa, Uncompahgre, and White River National Forests (Hoffman and Alexander 1980, 1983; Hoffman[5]). Powell[7] described a *P. tremuloides/P. aquilinum* community type on the Pike and San Isabel National Forests. Mueggler[9] described a *P. tremuloides/P. aquilinum* community type in northern Utah, but the successional status of that community type is uncertain. Hoffman and Alexander (1987) described a *P. tremuloides/Corylus cornuta* habitat type with a *P. aquilinum* phase in the Black Hills, but the composition of the undergrowth is so different that is appears unrelated to the *P. tremuloides/P. aquilinum* habitat type described here. The *P. tremuloides/P. aquilinum* habitat type has not been described elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988).

Management implications.—This habitat type is restricted to small stands, but timber productivity is average to above average. While clearcutting in small blocks or patches is the common practice used to regenerate aspen, it may create problems in this habitat type where drainage is poor by raising the water table. Moreover, the *P. tremuloides/P. aquilinum* habitat type

is most likely to occur in cold air drainage situations where *P. tremuloides* is subject to frost damage in cleared openings. Infiltration is less than in other *Populus*-dominated habitat types, and the potential for erosion, surface runoff, and mass movement is higher. The potential for soil damage from roadbuilding and logging equipment is high, especially when soils are wet.

Undergrowth production in this habitat type may be moderate to high, but it has low value for livestock forage because *P. aquilinum* is poisonous (oxalic acid) and unpalatable. It may be an indicator of soils capable of producing highly acidic vegetation. The *P. tremuloides/P. aquilinum* habitat type has low to moderate value for wildlife, because it lacks both structural diversity and palatable food species. Moreover, because most stands are open, the habitat type seldom qualifies as summer thermal cover. This habitat type has fair scenic quality where the shrub layer is developed well enough to provide seasonal color contrast.

Populus tremuloides/Thalictrum fendleri

Description.—The *Populus tremuloides/Thalictrum fendleri* habitat type, represented by only one stand, is found in the wettest situations associated with the *P. tremuloides* series in the Gunnison National Forest. Although the *P. tremuloides/T. fendleri* habitat type appears to be well represented on the Gunnison National Forest, it occupies considerably less area than the *P. tremuloides/Symphoricarpos oreophilus* habitat type. The sampled stand lies just below Rainbow Lake in the West Elk Mountains on gentle (7%) southeast-facing slope. Soils are a well-developed, moderately deep loam (table 1).

The *P. tremuloides/T. fendleri* habitat type is recognized by the constant reproductive success of *Populus tremuloides* and the high cover (35%) of *Thalictrum fendleri* in the undergrowth (fig. 22). *P. tremuloides* was the only tree species present in the sampled stand. Except for a few *Rosa woodsii*, shrubs are absent in this stand. Significant graminoids include *Bromus porteri, Carex geyeri, Elymus trachycaulis, Festuca idahoensis*, and *Poa epilis*. In addition to *T. fendleri*, important forbs are *Achillea lanulosa, Chamerion angustifolium, Cirsium* spp., *Erigeron speciosus, Fragaria virginiana, Helianthella quinquenervis, Lathyrus leucanthus, Lupinus argenteus*, and *Senecio serra*.

P. tremuloides/T. fendleri is one of the most widely distributed *P. tremuloides* habitat types in the central Rocky Mountains. In Colorado, it has been reported on the Grand Mesa and Uncompahgre National Forests by Hoffman,[5] on the White River National Forest by Hoffman and Alexander (1983) and Hess and Wasser,[2] on the Routt National Forest by Hoffman and Alexander (1980), on the Arapaho and Roosevelt National Forests by Hess and Alexander (1986), and on the San Juan National Forest by Johnston and Hendzel.[8] This habitat type also occurs on the Medicine Bow National Forest in southeastern Wyoming (Alexander et al. 1986). Mueggler[9] described a similar community type in southeastern Idaho, eastern Nevada, northern Utah, and western Wyoming. Powell[7] also described a *P. tremuloides/T. fendleri* community type on the Pike and San Isabel National Forests in Colorado. This habitat type appears closely related to the *P. tremuloides/Ligusticum porteri* habitat type found on the Pike, San Isabel, San Juan, and Uncompahgre National Forests (Johnston and Hendzel,[8] Powell[7]). These two habitat types may in fact be the same habitat type, but at present are distinguished by the amount of *L. porteri* cover, which often increases where the water table is near the surface or drainage is poor.

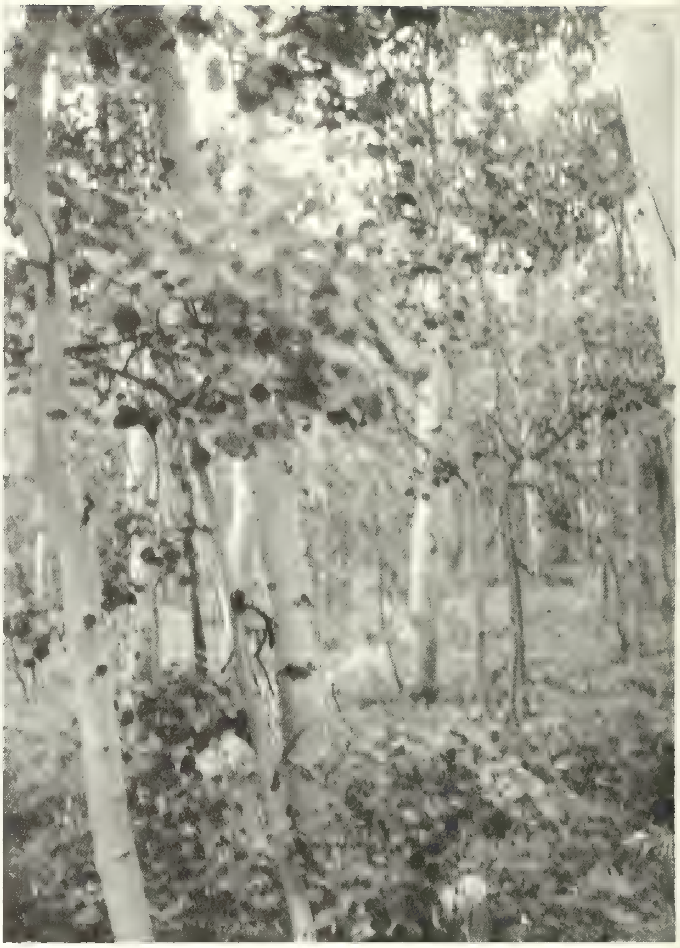

Figure 22.—*Populus tremuloides/Thalictrum fendleri* habitat type below Rainbow Lake, West Elk Mountains. *T. fendleri, Carex geyeri, Lathyrus leucanthus*, and *Lupinus argenteus* dominate the undergrowth.

Management implications.—The *P. tremuloides/T. fendleri* habitat type is the most productive for timber and forage in the *Populus* series. Site quality ranges from average to high. Clearcutting in patches or small blocks to effect regeneration of new stands is the most effective way to harvest these stands. Stands in this habitat type have moderate probability of being successfully burned, but only if livestock are excluded for at least one season before burning and fires are initiated after undergrowth vegetation has cured.

This habitat type is the best *Populus*-dominated habitat for big game and domestic sheep summer range. Although forage production under proper grazing

management can be as high as 3,000 pounds per acre (3,360 kg/ha) for the first few years after clearcutting, sustained production under a *Populus* overstory is closer to 1,500 pounds per acre (1,680 kg/ha). Much of the forage is better for sheep than cattle.

This habitat type is the "classic" *Populus*-forb rangeland that provides a significant amount of the forage produced on western ranges. However, heavy livestock use, especially by sheep, can reduce the cover of forbs and, consequently, usable forage production. With severe overuse, *Lathyrus leucanthus*, which is unpalatable to livestock, may increase at the expense of palatable forbs. Ultimately this habitat type can be degraded into a *P. tremuloides/L. leucanthus* disclimax that may not recover.

The *P. tremuloides/T. fendleri* habitat type also provides habitat for numerous nongame animals, but management implications for them are unknown. This habitat type has the most visually appealing foreground of all *Populus*-dominated habitat types because of the usually wide spacing of large-diameter trees and the abundance of wildflowers in the undergrowth. Soils are well developed, and erosion usually is not a problem, except on deteriorated ranges. In some situations, potential for soil mass movement appears to be high, especially on steeper slopes or if the overstory is removed in large clearcut blocks. Annual precipitation is 25 to 40 inches (64 to 102 cm), with about one-half becoming runoff. Potential for increasing streamflow under management is unknown. The potential for dispersed recreation is moderate, but the potential for developed recreation is low because of susceptibility of *P. tremuloides* to damage.

PINUS CONTORTA SERIES

The *Pinus contorta* series forms a major forest type throughout the Gunnison National Forest in the upper montane and lower subalpine zones, except in the southern part of the study area, at elevations of 7,745 to 10,660 feet (2,861 to 3,250 m) (table 1). *P. contorta*'s occurrence in the Gunnison National Forest and elsewhere in the Rocky Mountains usually is attributed to widespread and repeated fires. There has been less agreement on its successional status. Many ecologists and foresters considered *P. contorta* a seral species that, in the absence of fire, would be replaced by forests dominated by *Picea engelmannii* and *Abies lasiocarpa* at higher elevations, and *Pseudotsuga menziesii* and *Pinus ponderosa* at lower elevations (Clements 1910, Daubenmire 1943, Mason 1915).

More recently, investigators have concluded that *P. contorta* is climax, or at least a long-lived subclimax species, in certain topoedaphic situations, especially on cold sites with thin, excessively drained soils. Moir (1969) and Radloff (1983) reported it to be climax within the upper montane zone of the Front Range of Colorado. Hoffman and Alexander (1976, 1980), Hess and Alexander (1986), and Alexander et al. (1986) described climax *P. contorta* forests in the Bighorn Mountains, Wyoming, occurring on soils derived from granites, and on the Arapaho, Medicine Bow, Roosevelt, and Routt National Forests. Hess and Wasser[2] also described climax *P. contorta* stands on the White River National Forest. Climax *P. contorta* forests are described in the Wind River and Absaroka Mountains, western Wyoming, by Steele et al. (1983). Cooper et al. (1987), Pfister et al. (1977), and Steele et al. (1981) reported apparently stable and climax *P. contorta* forests in Montana and Idaho. Mauk and Henderson (1984) also described climax *P. contorta* forests in northern Utah. Alexander (1988) summarized all plant associations in the Intermountain and Rocky Mountain Regions in which *P. contorta* is climax.

In the Gunnison National Forest, *P. contorta* was infrequently encountered in *P. menziesii*-, *P. ponderosa*-, and *Populus tremuloides*-dominated forests, but it was a common seral species in *A. lasiocarpa-P. engelmannii* forests. Seral *P. contorta* is more likely to be even-aged and bear a high proportion of serotinous cones. Where *P. contorta* is the dominant self-reproducing species, it may exhibit a population structure of several age classes and is not adversely affected by competition from its common associates. Climax *P. contorta* stands are more likely to contain a higher proportion of trees bearing nonserotinous cones.

In some areas, especially on dry, thin, excessively drained soils, *P. contorta* forms dense dog-hair stands with little undergrowth. In these situations, *P. contorta* may be a seral species that will occupy the site for hundreds of years, either because there is no seed source of climax species available for reinvasion, or establishment of *A. lasiocarpa*, *P. engelmannii*, and *P. menziesii* is so slow and difficult that *P. contorta* will never be fully replaced.

This series is represented by four stands and three habitat types. Tree sizes for those stands where measurements are available ranged from seedlings to the 20- to 24-inch (5- to 6-dm) d.b.h. class. Tree size and plant species data for *P. contorta* stands are shown in tables A–1 and A–6.

Pinus contorta/Juniperus communis

Description.—The *Pinus contorta/Juniperus communis* habitat type, represented by two stands, occurs in the warmest sites occupied by the *P. contorta* series. One stand in Taylor Canyon is on a nearly level stream terrace. The other stand is in the Slaughterhouse Creek Valley, west of Tincup, on a gentle (9%) southeast-facing slope about 2,000 feet (610 m) higher in elevation than the first stand. This infrequent topographic climax is confined to warm, rocky sites. Soils are moderately deep, coarse-textured sandy loams derived from a variety of parent materials (table 1).

The *P. contorta/J. communis* habitat type is recognized by the dominance and reproductive success of *Pinus contorta* in the overstory, and the dominance of *Juniperus communis* (7–10% cover) in the undergrowth (fig. 23). *Picea engelmannii* and *Pseudotsuga menziesii* may occur occasionally, but there is no evidence of sufficient reproduction to replace *P. contorta*. Important shrubs in addition to *J. communis* are *Arctostaphylos adenotricha*

and *Rosa woodsii*. Major species in the depauperate herbaceous layer include *Calamagrostis purpurascens, Carex geyeri, Festuca idahoensis, Poa* spp., *Antennaria* spp., *Fragaria virginiana, Senecio neomexicana*, and *Selaginella densa*.

In Colorado, Hess and Alexander (1986) and Radloff (1983) described a *P. contorta/J. communis* habitat type on the Arapaho, Pike, and Roosevelt National Forests. This habitat type also occurs on the Medicine Bow National Forest in southeastern Wyoming (Alexander et al. 1986). In northwestern Wyoming and southwestern Idaho, Steele et al. (1983), and in northern Utah, Mauk and Henderson (1984) reported a *P. contorta/J. communis* community type that is similar to the habitat type described above, except that its successional status is unclear. This habitat type was not described on the Routt nor the White River National Forests (Hess and Wasser;[2] Hoffmann and Alexander 1980, 1983)). The *P. contorta/J. communis* habitat type is closely related to the *P. contorta/Arctostaphylos uva-urai* (*A. adenotricha*) habitat type described on the Pike National Forest (Radloff 1983), Bighorn National Forest in Wyoming (Hoffman and Alexander 1976), and in northern Utah (Mauk and Henderson 1984). The two habitat types can be difficult to distinguish when both *J. communis* and *A. adenotricha* are present.

Figure 23.—*Pinus contorta/Juniperus communis* habitat type in Slaughterhouse Creek Valley west of Tincup. *Carex geyeri* is the principal undergrowth associate of *J. communis*.

Management implications.—The *P. contorta/J. communis* habitat type has the lowest timber production potential of the *P. contorta* series. Regeneration is likely to be more difficult to obtain in this dry habitat type than in other *P. contorta*-dominated habitat types. Clearcutting or shelterwood cutting can be used in sawlog-sized stands regardless of cone habit. Scarification may improve natural regeneration success by reducing competitive vegetation, thereby conserving soil moisture. On south slopes and in tension zones, a long regeneration period usually follows clearcutting because of limited soil moisture. In those situations, a standard shelterwood system is more likely to result in regeneration success, but a shelterwood should not be used in dwarf mistletoe-infested stands. On other aspects, clearcutting usually is successful but can result in either too much or too little reproduction, depending on the cone habitat, amount of seed available, and slash disposal treatment (Alexander 1974, 1986b).

If a clearcut option is used in stands with nonserotinous cones, openings should be limited to small [3- to 5-acre (1- to 2-ha)] patches or narrow [400-foot (122-m) wide] strips where natural regeneration is desired. Large clearcut openings will require fill-in planting. In stands with serotinous cones, clearcut openings up to 40 acres (16 ha) may be used if the stand is heavily infested with dwarf mistletoe or infested with mountain pine beetles. Care must be used in slash disposal in these stands so that the seed source is not destroyed. Group selection cutting is a possibility in stands with irregular structure, but individual-tree selection cutting generally is appropriate only in recreation and critical wildlife areas when the objective is to create multistoried stands.

In young *P. contorta* pole stands, thinning is needed to reduce basal area and improve soil moisture. Growing stock levels (GSL) of 80 to 120 are most appropriate for timber production (Alexander and Edminster 1981). Forage production usually is increased slightly for a short time following clearcutting, but the potential for increasing forage production for either livestock or big game is low in this habitat type. Natural runoff in the *P. contorta/J. communis* habitat type is at least 8 inches (20 cm) annually. Much of the precipitation falls as snow. Streamflow can be increased by clearcutting in small patches, or using group shelterwood and group selection when the openings are near the maximum size [2 acres (0.8 ha)].

Pinus contorta/Carex geyeri

Description.—The *Pinus contorta/Carex geyeri* habitat type occurs in more mesic environments than the *P. contorta/Juniperus communis* habitat type. The *P. contorta/C. geyeri* habitat type occurs at the lowest elevations [7,800 feet (2,361 m)] in the *P. contorta* series (table 1). This habitat type was sampled in one stand on the west side of Marshall Pass on a gentle (3%) south-facing slope, but it commonly occurs throughout the *P. contorta* zone in Colorado. Soils in the sampled stand are a sandy loam.

This habitat type is recognized by the overstory dominance and reproductive success of *Pinus contorta*, and the dominance and abundance of *Carex geyeri* (40–65% cover) in the undergrowth (fig. 24). The sparse shrub layer is represented by *Ribes montigenum*, *Rosa woodsii* and *Symphoricarpos oreophilus*. Herbaceous vegetation dominates the undergrowth. In addition to *C. geyeri*, *Bromus porteri*, *Calamagrostis canadensis*, *Festuca saximontana*, *Achillea lanulosa*, *Arnica cordifolia*, *Astragalus alpinus*, *Erigeron subtrinervis*, *Fragaria virginiana*, and *Thermopsis montana* have significant cover.

A *P. contorta/C. geyeri* habitat type has been reported in Colorado on the Arapaho and Roosevelt National Forests by Hess and Alexander (1986), on the White River National Forest by Hess and Wasser,[2] and on the Medicine Bow National Forest in Wyoming by Alexander et al. (1986). Hoffman and Alexander (1976, 1980, 1983) did not identify this habitat type on either the Routt or White River National Forest in Colorado, or in the Bighorn Mountains of north-central Wyoming; but, *P. contorta* is a long-lived seral member of the *A. lasiocarpa/C. geyeri* habitat type on these forests. *P. contorta*-dominated stands seral to the *A. lasiocarpa/C. geyeri* habitat type are less evident on the Gunnison National Forest. In northwestern Wyoming and central Idaho, Steele et al. (1981, 1983) reported a *P. contorta/C. geyeri* community type that has similar characteristics, although there are some differences in floristic composition.

Figure 24.—*Pinus contorta/Carex geyeri* habitat type, west side of Marshall Pass. Undergrowth is dominated by *C. geyeri*, but *Arnica latifolia* and *Fragaria virginiana* are well represented.

Management implications.—Timber productivity in this habitat type is average to below average. Site indexes are likely to be below average (Alexander 1966). Even-aged management, under either a clearcutting or shelterwood alternative, is recommended for most stands (Alexander 1986b). However, natural regeneration may be difficult to obtain after clearcutting because the *C. geyeri*-dominated undergrowth competes severely with tree seedlings. A shelterwood cutting alternative has the advantage of better control over undergrowth development and may better meet wildlife cover and visual requirements.

Although most stands in the *P. contorta/C. geyeri* habitat type bear serotinous cones, clearcutting in large openings is not recommended, even in those situations where stands are infested with dwarf mistletoe or susceptible to attack by mountain pine beetles, because competition between seedlings and *C. geyeri* offsets the probable reduction in insect and disease losses by increasing the likelihood that large openings will take a long time to regenerate. A better option would be to use the opening size recommended for stands with nonserotinous cones.

Regardless of the size of opening, in stands with serotinous cones care must be used in slash disposal and seedbed preparation so that the seed source is not destroyed.

Uneven-aged management under individual-tree or group selection cutting can reduce stand susceptibility to mountain pine beetles by removing the most susceptible host trees. Group selection cutting is a possibility in stands with irregular structure, but individual-tree selection in stands not attacked by mountain pine beetles generally is appropriate only in recreation areas. Growth will be substantially reduced, however, with either uneven-aged cutting method.

In young *P. contorta* pole stands, thinning is needed to reduce basal area to improve growth and soil moisture. GSLs of 100 to 120 are most appropriate for timber production (Alexander and Edminster 1981). Forage production is fair to poor and not likely to be improved by cutting. Wildlife habitat is poor, and the potential for increasing it is low. Big game use is limited, and nongame bird and small mammal populations are sparse. Stands often are dominated solely by *P. contorta* and *C. geyeri*.

Natural runoff in the *P. contorta/C. geyeri* habitat type is 8 to 10 inches (20 to 25 cm) annually. Much of the precipitation falls as snow. Streamflow can be increased substantially by clearcutting about one-third of the area in small [3- to 5-acre (1- to 2-ha)] patches interspersed with uncut timber (Leaf 1975, Leaf and Alexander 1975, Troendle 1983, Troendle and King 1985). If larger openings are cut, slash should be left in place to create surface roughness needed to retain the snowpack. Streamflow also can be increased by partial cutting on north slopes, but runoff may be less than with clearcutting (Troendle and Meiman 1984). Group shelterwood and group selection cutting can be nearly as favorable for water produc-

tion as clearcutting if the openings are near the maximum size [2 acres (1 ha)].

Pinus contorta/Vaccinium scoparium

Description.—The *Pinus contorta/Vaccinium scoparium* habitat type was sampled in only one stand on the Gunnison National Forest, but it extends to the upper altitudinal limits of the *P. contorta* series throughout Colorado. It grows on sites that appear too shallow, rocky, and well drained to permit establishment of *Abies lasiocarpa* and *Picea engelmannii* in sufficient numbers to replace *P. contorta*. The stand sampled is below Old Monarch Pass on a gentle (9%) west-facing slope. Soils are a shallow sandy loam (table 1).

This habitat type is recognized by the overstory dominance and reproductive success of *Pinus contorta*. The presence of an occasional *Abies lasiocarpa* and *Picea engelmannii* is not sufficient to indicate replacement of *P. contorta*. The depauperate undergrowth is dominated by *Vaccinium scoparium* (18% cover) (fig. 25). The only other shrub in the sampled stand was *Juniperus communis*. Herbaceous vegetation, which is unconspicuous and poorly represented, includes *Carex brevipes, Poa pratensis, Antennaria* spp., *Sedum lanceolatum, Senecio neomexicanus*, and *Solidago multiradiata*.

A *P. contorta/V. scoparium* habitat type was reported in the Bighorn Mountains by Hoffman and Alexander (1976), on the Arapaho and Roosevelt National Forests by Hess and Alexander (1986), and on the Medicine Bow National Forest by Alexander et al. (1986). Although Hoffman and Alexander (1980, 1983) did not report this habitat type on the Routt National Forest or on the White River National Forest, they described an *A. lasiocarpa/V. scoparium* habitat type that had *P. contorta* as a long-lived seral. A similar community type was reported in Montana by Pfister et al. (1977), in central Idaho by Steele et al. (1981), in northwestern Wyoming by Steele et al. (1983), in northern Idaho by Cooper et al. (1987), and in the Uinta Mountains, Utah, by Mauk and Henderson (1984).

Figure 25.—*Pinus contorta/Vaccinium scoparium* habitat type below Old Monarch Pass, Sawatch Range. *V. scoparium* and *Juniperus communis* are the principal undergrowth species.

Management implications.—Site indexes and timber productivity in the *P. contorta/V. scoparium* habitat type are the highest in the *P. contorta* series (Alexander 1966), but are average to below average and much lower than in stands of *P. contorta* that are seral to *Abies lasiocarpa* and *Picea engelmannii*. Even-aged management under either a clearcutting or shelterwood cutting alternative is recommended for most stands (Alexander 1986b). A shelterwood system has the advantages of meeting wildlife cover and visual management requirements, while at the same time providing shade needed to conserve soil moisture and control overstocking. It also provides some control over dwarf mistletoe and bark beetles, although clearcutting is a more effective silvicultural pest control. Clearcutting can result in either too much or too little reproduction, depending on the cone habit, amount of seed available, climatic factors, and slash disposal treatments (Alexander 1974, 1986b).

If a clearcut option is used in stands with nonserotinous cones, openings should be 3- to 5-acre (1- to 2-ha) patches or narrow 400-foot (122-m) wide strips where natural regeneration is desired. Large clearcut openings will require fill-in planting. In stands with serotinous cones, clearcut openings up to 40 acres (16 ha) may be used if the stand is heavily infested with dwarf mistletoe or infested with mountain pine beetles. However, smaller openings, 5 to 20 acres (2 to 8 ha), better meet the objectives of multiresource management. Care must be used in slash disposal so that the seed source is not destroyed.

Uneven-aged management under individual-tree or group selection cutting can reduce stand susceptibility to mountain pine beetles by removing the most susceptible host trees. Group selection cutting is a possibility in stands with irregular structure, but individual tree selection in stands not attacked by mountain pine beetles generally is appropriate only in recreation and wildlife areas. Growth will be substantially reduced, however, with either uneven-aged cutting method.

Poletimber stands in this habitat type have better spacing and crown class differentiation than in other *P. contorta*-dominated habitat types. Thinning to GSLs of 120 to 160 is most appropriate for individual tree and stand growth (Alexander and Edminster 1981).

The *P. contorta/V. scoparium* habitat type is fair high-elevation summer range for wildlife. Forage production is moderate to fair for livestock and big game but can be increased substantially [to 500 pounds per acre (560 kg/ha)] for short periods of time after clearcutting, provided that there is a good response by herbaceous vegetation. Larger increases may be possible but are not likely because sites are cold, with a short growing season. Natural runoff in the *P. contorta/V. scoparium* habitat type is 12 to 15 inches (30 to 38 cm). Much of the precipitation falls as snow. Streamflow can be increased substantially by clearcutting about one-third of the area in small [3- to 5-acre (1- to 2-ha)] patches interspersed with uncut timber (Leaf 1975, Leaf and Alexander 1975, Troendle 1983, Troendle and King 1985). If larger openings are cut, slash should be left in place to create surface roughness needed to retain the snowpack. Streamflow also can be increased by partial cutting on north slopes,

but runoff may be less than with clearcutting (Troendle and Meiman 1984). Group shelterwood and group selection cutting can be nearly as favorable for water production as clearcutting if the openings are near the maximum size. The potential for developed and dispersed recreation is moderate because of the elevations at which this habitat type occurs and the limited acreage.

PINUS FLEXILIS SERIES

The *Pinus flexilis* series is relatively rare on the Gunnison National Forest. It usually occurs on exposed, windswept, concave rocky ledges and ridgetops. The *P. flexilis* series was sampled in only one well-developed stand at 9,005 feet elevation (2,744 m) (table 1). Tree size data are not available for this series. Plant species data for *P. flexilis* are shown in table A–7.

Pinus flexilis/Ciliaria austromontana

Description.—The *Pinus flexilis/Ciliaria austromontana* (*Saxifraga bronchialis*) habitat type was sampled in only one stand on a steep (53%) southwest-facing canyon side in Spring Canyon. Soils are a shallow sandy loam (table 1).

The *P. flexilis/C. austromontana* habitat type is recognized by the overstory dominance and reproductive success of *Pinus flexilis*, and the abundance of *Ciliaria austromontana* (10% cover) in the undergrowth (fig. 26). *Pseudotsuga menziesii* is an occasional tree associate. The shrub layer includes *Juniperus communis, Ribes inerme, Rosa woodsii*, and *Symphoricarpos oreophilus*. Graminoids with significant cover are *Agrostis hiemalis, Carex geophila, Festuca thurberi, Poa nemoralis* ssp. *interior*, and *Poa reflexa*. In addition to *C. austromontana, Fragaria virginiana* is the only forb with significant cover.

The *P. flexilis/C. austromontana* habitat type has not been reported elsewhere in Colorado (Alexander 1987) or in the Rocky Mountain and Intermountain regions (Alexander 1988). This habitat type is somewhat similar to the *P. flexilis/J. communis* habitat type reported on the Arapaho and Roosevelt National Forests by Hess and Alexander (1986), except that the composition of the forb layer is different.

Management implications.—This dry habitat type has very low productivity for timber production because of low stand density and slow tree growth. Forage value for big game is low to moderate; the habitat type is probably used by mule deer in the spring and fall. Overstory trees adjacent to grasslands may provide cover for wildlife. The rocky ridges with sparse tree canopy can be important transitional range for bighorn sheep. *P. flexilis* seeds are large and are food for birds and small mammals. High surface temperatures and low soil moisture may impede regeneration or revegetation, especially on disturbed areas. There is little or no potential for increasing streamflow, but the *P. flexilis/C. austromontana* habitat type provides watershed protection.

Figure 26.—*Pinus flexilis/Ciliaria austromontana* habitat type, Spring Creek Canyon. *C. austromontana, Rosa woodsii, Symphoricarpos oreophilus*, and *Festuca thurberi* are important undergrowth species.

PINUS ARISTATA SERIES

Pinus aristata is not a major forest tree species on the Gunnison National Forest. It occurs mainly in the southern part of the study area, with the largest stands centered around Cochetopa Pass, at elevations ranging from 9,940 to 11,865 feet (2,878 to 3,616 m) (table 1). Small isolated stands occur further north. This series is represented by seven stands and three habitat types. Tree sizes for those stands where measurements were made ranged from seedlings to the ≥28-inch (≥7-dm) d.b.h. class. Tree populations and plant species data for *P. aristata* are shown in tables A–1 and A–7.

Pinus aristata/Festuca thurberi

Description.—The *Pinus aristata/Festuca thurberi* habitat type was sampled in one stand below Cumberland Pass on a moderate (21%) west-facing slope. Soils are shallow and loamy (table 1).

Figure 27.—*Pinus aristata/Festuca thurberi* habitat type below Cumberland Pass, Sawatch Range. *F. thurberi* accounts for most of the undergrowth.

The *P. aristata/F. thurberi* habitat type is recognized by the overstory dominance and reproductive success of *Pinus aristata*. *Picea engelmannii* is a minor codominant in the sampled stand. *Festuca thurberi* has the highest coverage (15%) in the undergrowth (fig. 27). *Juniperus communis* and *Ribes montigenum* were the only shrubs present. In addition to *F. thurberi*, other graminoids include *Elymus trachycaulus*, *Koeleria macrantha*, and *Poa glauca*. The forb layer is a rich mixture of species, but no individual species had more than 2% cover. The *P. aristata/F. thurberi* habitat type has been reported in southern Colorado and northern New Mexico (DeVelice et al. 1986). It has not been reported elsewhere in Colorado (Alexander 1987) or in the Rocky Mountain and Intermountain regions (Alexander 1988).

Management implications.—Timber productivity in this habitat type is very low because of poor site quality and low stand density; *Pinus aristata* is the oldest and slowest growing tree in the Rocky Mountains, with a maximum age of about 1,600 years. Stands in the *P. aristata/F. thurberi* habitat type generally have a park-like appearance, with widely spaced trees or occasional groups of trees interspersed with *Festuca*-dominated meadows. The potential for forage production is high on sites with high cover of *F. thurberi*. Forage is more palatable to cattle than sheep, but stands usually are not important rangelands because *F. thurberi* is only moderately palatable to cattle and only in the early season. Moreover, the generally remote locations of this habitat type make access difficult. The *P. aristata/F. thurberi* habitat type is important summer range for elk. This habitat type also is important for watershed protection. It is esthetically valuable because of the usually pleasing appearance of the old and gnarled *P. aristata*.

Pinus aristata/Juniperus communis

Description.—The *Pinus aristata/Juniperus communis* habitat type was sampled in one stand near Cochetopa Pass on a moderate (14%) southeast-facing slope below a rocky ridge. The soil is a shallow sandy loam (table 1).

The *P. aristata/J. communis* habitat type is recognized by the overstory dominance and reproductive success of *Pinus aristata*, and the presence and abundance of *Juniperus communis* (16% cover) in the undergrowth (fig. 28). *Pinus flexilis* is an overstory associate. Major shrubs are *J. communis* and *Rosa woodsii*. The most important graminoids are *Carex geyeri*, *Koeleria macrantha*, *Muhlenbergia montana*, and *Poa fendleriana*. Forbs with the highest coverage include *Androsace septentrionalis*, *Artemisia dracunculus*, *Artemisia frigida*, and *Erigeron subtrinervis*. This habitat type has not been identified elsewhere in Colorado (Alexander 1987) or in the Rocky Mountain and Intermountain regions (Alexander 1988).

Management implications.—Timber productivity is very low in this habitat type. Trees are open grown, short, and slow growing. The potential for forage production is low because of the paucity of palatable forage species. The habitat type may have some use as summer elk habitat and transitory bighorn sheep range. The *P. aristata/J. communis* habitat type provides watershed production and scenic beauty.

Figure 28.—*Pinus aristata/Juniperus communis* habitat type below Cochetopa Pass, Cochetopa Hills. *J. communis*, *Koeleria macrantha*, and *Poa fendleriana* are the principal undergrowth species.

Pinus aristata/Festuca arizonica

Description.—The *Pinus aristata/Festuca arizonica* habitat type is represented by five stands. Two of these stands (160, 229) were originally classified by Karmakova[3] as a *Pinus aristata/Muhlenbergia montana* habitat type. This habitat type is the most widespread in the *P. aristata* series. Sampled stands are located below Cochetopa Pass and in Cebolla Creek Canyon, on gentle (9%) to steep (51%) slopes with southern to eastern aspects. Soils are shallow sandy loam (table 1).

The *P. aristata/F. arizonica* habitat type is recognized by the overstory dominance and reproductive success of *Pinus aristata*. *Populus tremuloides*, *Picea pungens*, and *Pinus flexilis* are occasional tree associates. The undergrowth is dominated by *Festuca arizonica* (9–20% cover) and *Muhlenbergia montana* (2–25% cover) (fig. 29). The major shrub species is *Ribes cereum*. In addition to *F. arizonica* and *M. montana*, graminoids with significant cover are *Carex geyeri*, *Danthonia parryi*, *Elymus elymoides*, and *Koeleria macrantha*. Forbs are sparse, with *Artemisia frigida* and *Geranium caespitosum* having the highest cover. The *P. aristata/F. arizonica* habitat type has been reported in the San Juan National Forest and Sangre de Cristo Mountains of northern New Mexico (DeVelice et al. 1986). It has not been identified elsewhere in Colorado (Alexander 1987) or in the Rocky Mountain and Intermountain regions (Alexander 1988).

Management implications.—Timber productivity and stand conditions in the *P. aristata/F. arizonica* habitat type are similar to other habitat types in the *P. aristata* series. The potential for forage production is high, because both *F. arizonica* and *M. montana* have high cover. Both species are more palatable to cattle than sheep. Moreover, the stands in this habitat type are accessible to livestock, except when they occur on steep slopes. The *P. aristata/F. arizonica* habitat type is sum-

mer range for elk, providing both food and cover. This habitat type provides watershed protection and a pleasing esthetic appearance.

ABIES LASIOCARPA SERIES

The *Abies lasiocarpa* series represents the subalpine zone throughout the Gunnison study area. It occupies the highest and coldest coniferous forest zone on the Gunnison National Forest, dominated by *A. lasiocarpa* and *Picea engelmannii* (table 1). Throughout much of the Rocky Mountains, the subalpine forest zone is widespread and supports forests of considerable importance. On the Gunnison National Forest, it is found on all aspects at elevations ranging from 8,835 to 11,540 feet (2,693 to 3,517 m), a span of 2,705 feet (824 m) (table 1). It has been reported as low as 8,000 feet (2,440 m) to as high as 11,800 feet (3,870 m) in the central Rocky Mountains. On the Gunnison National Forest, the lower elevational limits of *A. lasiocarpa-Picea engelmannii*-dominated forests and the upper elevational limits of the *Pinus contorta*-dominated forests overlap considerably. The upper limit of *Populus tremuloides* also overlaps somewhat, but is below the upper limit of *Pinus contorta*. Aspect and soils also play some part in the distribution of forest tree species.

Figure 29.—*Pinus aristata/Festuca arizonica* habitat type in Cebolla Creek Canyon. *F. arizonica* and *Muhlenbergia montana* dominate the undergrowth.

Although *Picea engelmannii* may be the climax or sole dominant on some plots sampled, the habitat types described in this series are all named for *Abies lasiocarpa* as the climax dominant to be consistent with usage elsewhere (Alexander et al. 1986; Daubenmire and Daubenmire 1968; Hess and Alexander 1986; Hoffman and Alexander 1976, 1980, 1983; Mauk and Henderson 1984; Pfister et al. 1977; Steele et al. 1981, 1983). On the Gunnison National Forest, *P. engelmannii* usually is a co-climax dominant with little evidence that it will ever be completely replaced by *A. lasiocarpa*. Young *A. lasiocarpa* often outnumber the young *P. engelmannii*, because *A. lasiocarpa* is more tolerant and reproduces by layering and from seed, whereas *P. engelmannii* reproduces almost entirely from seed. Because *P. engelmannii* live longer, they are nearly always the largest trees in the stand. An exception occurs in stands where *P. engelmannii* has been severely attacked by the spruce beetle (*Dendroctonus rifipennis* Kirby) (Schmid and Hinds 1974). In some instances, *P. engelmannii* may be the dominant species in both the overstory and the understory. Moreover, some stands may contain only *A. lasiocarpa* or *P. engelmannii*.

In many stands, *P. contorta* and/or *P. tremuloides* are present as seral species. After disturbance, *P. tremuloides* may establish initially to be succeeded by *P. contorta*, which in turn is replaced by *A. lasiocarpa* and *P. engelmannii*. *P. tremuloides* or *P. contorta* may establish after disturbance and be directly replaced by *A. lasiocarpa* and *P. engelmannii*. *A. lasiocarpa* and *P. engelmannii* can reestablish immediately with or without *P. contorta* and/or *P. tremuloides*, depending on the topographic situation, the type of disturbance, and the availability of coniferous tree seed or the sprouting capacity of *Populus*.

The Gunnison National Forest is near the southeastern limit of the natural distribution of *P. contorta*. To the south in the Rocky Mountains, there is no comparable seral tree species in the *A. lasiocarpa* series above the upper limit of *P. tremuloides* stands. On the western slope of Colorado, *P. contorta*'s distribution is nearly the complement of *P. ponderosa*, in areal extent and elevation. Based on the distribution of tree species, there appears to be a major climatic break in forest composition near the southern boundary of the Gunnison National Forest. This change in climate is paralleled by the gradual replacement of *Vaccinium scoparium*, a common undergrowth species in subalpine forests to the north, by *V. myrtillus*, a common undergrowth species in subalpine forests to the south. This break also coincides with the gradual replacement of *Carex geyeri*, common to the north, by other *Carex* species to the south.

This series is represented by 19 stands and nine habitat types.[10] In those stands where measurements were made, tree sizes ranged from seedlings to the ≥28-inch (≥7-dm) d.b.h. class. Tree size and plant species data for *A. lasiocarpa* stands are shown in tables A–1 and A–8.

[10]*Komarkova*[3] *identified an Abies lasiocarpa/Salix glauca (Abies lasiocarpa-Picea engelmannii/Salix glauca) habitat type on the Gunnison National Forest. It is omitted from this paper because it is krummholz, not a forest habitat type.*

Abies lasiocarpa/Carex geyeri

Description.—The *Abies lasiocarpa/Carex geyeri* habitat type is represented by four stands located on warm, moderately dry sites ranging from the upper montane to the middle subalpine zones. Two of the sampled stands, near the Overland Reservoir and in the East Fork Creek Valley of the West Elk Creek Mountains, are in climax *Abies lasiocarpa-Picea engelmannii* stands. The third and fourth stands, on Alpine Plateau and in Gold Creek Valley, northwest of Pitkin, are late-seral *Populus tremuloides-A. lasiocarpa/C. geyeri* (stand 178) and *Pinus contorta/Carex geyeri* (stand 234) community types successional to the *A. lasiocarpa/C. geyeri* habitat type. In Komarkova's[3] original classification, stand 234 was identified as a *P. contorta/C. geyeri* habitat type, but *P. contorta* shows no evidence of self-perpetuation. These stands are on gentle (2–7%) east- to southeast-facing slopes. Soils are loamy to sandy loams (table 1).

This habitat type is distinguished by the dominance of *Carex geyeri* in the undergrowth, and the scarcity or near absence of *Vaccinium myrtillus* and *Vaccinium scoparium* (fig. 30). The overstory dominants are *Abies lasiocarpa* and *Picea engelmannii*. *Pinus contorta* and *Populus tremuloides* are common overstory seral species that may dominate mid to late seral stages, but neither species shows any significant evidence of long-term self-perpetuation. *Pseudotsuga menziesii* occurred as an occasional in one stand. Important undergrowth species in addition to *Carex geyeri* (3–65% cover) are *Juniperus communis, Mahonia repens, Paxistima myrsinites, Vaccinium caespitosum, Arnica cordifolia, Arnica latifolia, Fragaria virginiana, Lathyrus leucanthus, Thalictrum fendleri*, and *Veronica americana*. The high cover of *P. myrsinities* (18%) in one stand (234) suggests the possibility that this seral stand may ultimately develop into an *Abies lasiocarpa/Paxistima myrsinites* habitat type. However, the site characteristics are not what is normally associated with *P. myrsinites*-dominated undergrowth. Additional sampling is needed to confirm the occurrence of an *A. lasiocarpa/P. myrsinites* habitat type on the Gunnison National Forest.

Figure 30.—*Abies lasiocarpa/Carex geyeri* habitat type near Overland Reservoir, Paonia District. *Lupinus argenteus* is the principal undergrowth associate of *C. geyeri*.

The *A. lasiocarpa/C. geyeri* habitat type was described in the Routt National Forest by Hoffman and Alexander (1980), in the White River National Forest by Hoffman and Alexander (1983) and Hess and Wasser,[2] in the Arapaho National Forest by Hess and Alexander (1986), in the Grand Mesa and Uncompahgre National Forests by Hoffman,[5] and in the Medicine Bow National Forest by Alexander et al. (1986). This habitat type also has been reported in western Wyoming in Yellowstone National Park and the Teton National Forest (Steele et al. 1983), and in the mountains of central and southern Utah (Youngblood and Mauk 1985). In Montana, *A. lasiocarpa/C. geyeri* is a minor habitat type, occurring on cold, dry sites (Pfister et al. 1977) but is common in central Idaho on granitic soils (Steele et al. 1981).

Management implications.—In stands where *P. tremuloides* is present as a seral species in the *A. lasiocarpa/C. geyeri* habitat type, it usually sprouts vigorously after disturbance. These stands typically produce large amounts of undergrowth vegetation quickly after disturbance (Johnston and Hendzel[8]). *P. tremuloides* may dominate a long midseral stage in which there are a number of cycles of *Populus* before *A. lasiocarpa* and *P. engelmannii* dominate, especially in the absence of a conifer seed source. These stands may have high value as livestock forage and wildlife habitat. They are high-quality, summer range for deer and elk, and the mixed stand of *P. tremuloides* and seedling-sapling conifers provides a large diversity of habitats for birds and small mammals. Where *P. tremuloides* is a desirable species for timber management, these stands provide an excellent opportunity for manipulative management directed toward maintaining *P. tremuloides* in the stand, since they occupy more stable sites than climax *P. tremuloides* habitat types. In addition, there are substantial forage and wildlife benefits associated with arresting natural succession.

Stands where *Pinus contorta* is seral in the *A. lasiocarpa/C. geyeri* habitat type are not common on the Gunnison National Forest; but where they occur, undergrowth vegetation recovers slowly from major disturbance. Reproduction of conifers is more difficult to obtain, and competition between tree seedlings and undergrowth vegetation is more evident than in the *A. lasiocarpa/Vaccinum scoparium* habitat type. In fact, if tree seedlings

are slow to establish after clearcutting, the site may become fully occupied by *C. geyeri*. *P. contorta* will likely be better able to compete successfully with *C. geyeri* following major disturbance than either *A. lasiocarpa* or *P. engelmannii*.

Stands where *P. contorta* is seral have limited potential for forage production and wildlife. Moreover, soils exposed as a result of management activities may be more difficult to revegetate than soils where *P. tremuloides* is seral. Timber productivity for *P. contorta*, *A. lasiocarpa*, and *P. engelmannii* is average to below average. Productivity for *P. tremuloides* may be moderately high. Cutting methods applicable are similar to those suggested for the *A. lasiocarpa/V. scoparium* habitat type; however, seral stands of *P. contorta* are more likely to be susceptible to mountain pine beetle in the *A. lasiocarpa/C. geyeri* habitat type (Alexander 1986a). Where there is an appreciable amount of either *P. contorta* or *P. tremuloides* in the stands, clearcutting or simulated shelterwood is likely to increase their representation in the new stand. GSLs of 120 to 140 are most appropriate for climax stands managed for timber (Alexander and Edminster 1980).

Natural runoff [12 to 15 inches (30 to 38 cm)] usually is less than in the *A. lasiocarpa/V. scoparium* habitat type but can be increased significantly using the same cutting methods suggested for *A. lasiocarpa/V. scoparium* habitat type. The potential for dispersed recreation is moderate, but developed recreation may be high where *P. tremuloides* is seral because of site stability combined with high visual values. However, care must be exercised to minimize damage to *P. tremuloides* that can result in subsequent decay and eventual death of the stand. Potential for developed recreation in stands without *P. tremuloides* is moderate.

Abies lasiocarpa/Vaccinium scoparium

Description.—Although the *Abies lasiocarpa/Vaccinium scoparium* habitat type occurs extensively throughout the central Rocky Mountains, it is found only to a limited extent at higher elevations on the Gunnison National Forest. Most *A. lasiocarpa-Picea engelmannii*-dominated stands in the study area with *Vaccinium* have *Vaccinium myrtillus* in their undergrowth; the transition occurs from north to south at the approximate middle of the study area. The *A. lasiocarpa/V. scoparium* habitat type is represented by only one stand near Schofield Pass on a moderate (12%) northwest-facing slope. Soils are shallow, coarse-textured sandy loams (table 1).

The habitat type is recognized by the almost constant presence and reproductive success of *Abies lasiocarpa*, and by the abundance and undergrowth dominance of *Vaccinium scoparium*, sometimes in association with *Vaccinium myrtillus*. *Picea engelmannii* is present as a self-reproducing co-climax species (fig. 31). The overstory of most of the stands is dominated by *P. engelmannii*, with *A. lasiocarpa* as a codominant. *Pinus contorta* is an important seral species and still dominates some of the stands in late stages of succession. However, the

Figure 31.—*Abies lasiocarpa/Vaccinium scoparium* habitat type near Schofield Pass. *Vaccinium myrtillus* is the principal undergrowth associate of *V. scoparium*.

self-reproducing species in these stands are *A. lasiocarpa* and *P. engelmannii*. *Populus tremuloides* is only an occasional seral species. Ground cover varies from sparse to luxuriant. In general, undergrowth species richness declines as stands progress from seral to climax and from young to old. In addition to *V. scoparium* and *V. myrtillus*, which constitute more than 50% of the cover, other important undergrowth species include *Ribes coloradense*, *Arnica cordifolia*, *Caltha leptosepala*, *Castilleja rhexifolia*, *Pedicularis racemosa*, *Polemonium pulcherrimum*, and *Senecio triangularis*.

The *A. lasiocarpa/V. scoparium* habitat type, or others very similar to it, occur throughout the northern and central Rocky Mountains (Alexander et al. 1986; Cooper et al. 1987; Hess and Alexander 1986; Hoffman;[5] Hoffman and Alexander 1976, 1980, 1983; Mauk and Henderson 1984; Moir and Ludwig 1979; Pfister et al. 1977; Steele et al. 1981, 1983). However, there is considerable variability in the cover of *V. scoparium* within this habitat type. Additionally, more broad-leaved herbaceous dicots occur in this habitat type on the western slope of the Rocky Mountains than on the eastern slope.

Management implications.—Timber productivity for the climax species in the *A. lasiocarpa/V. scoparium* habitat type varies considerably (Alexander 1967). Productivity for *P. contorta* can be moderately high. Undergrowth vegetation changes slowly after major disturbance, and competition is not severe between tree seedlings and undergrowth vegetation, except where cover of herbaceous dicots is high. *P. engelmannii* reproduction may be difficult to obtain on south slopes and other dry situations. There may be a manageable stand of advanced *Abies* and *Picea* reproduction in much of this habitat type, especially in late seral stages.

While most silvicultural systems can be used (Alexander 1986a), complete removal of the mature overstory by clearcutting in mixed stands, where *P. contorta* makes up part of the overstory, may result in an even-aged replacement stand of seral *P. contorta*. This also can happen with the final harvest cut under shelterwood methods, unless extreme care is taken in logging to protect advanced regeneration of *A. lasiocarpa* and *P.*

engelmannii. In these mixed stands, using a standard or modified shelterwood system, the proportion of *P. contorta* retained in the first cut can be used to manipulate the amount of *A. lasiocarpa* and *P. engelmannii* in the stand. Clearcutting, even in small 3- to 5-acre (1- to 2-ha) or 400-foot wide (122-m) openings, is likely to eliminate the chance for regeneration of *P. engelmannii* on southerly exposures for extremely long periods of time. GSLs of 120 to 160 are appropriate for stands managed for timber (Alexander and Edminster 1980).

Where protection from direct solar radiation and reduction of excessive moisture losses from soil and seedlings are necessary for survival of *P. engelmannii*, standard or modified shelterwood is an appropriate even-aged cutting method (Alexander 1977, 1986c, 1986d). *P. contorta* may have to be planted on south aspects to maintain forest cover if clearings occur or are desired in this habitat type.

Uneven-aged management with group and/or individual-tree selection cutting can be used in irregular-structured stands, or where the combination of openings and high forest is required to enhance recreational opportunities and other amenities. Group selection is likely to perpetuate the existing species mix, but may increase the proportion of *P. contorta*.

Individual-tree selection will favor *A. lasiocarpa* over *P. engelmannii*, in mixed stands containing *P. contorta*; the proportion of both *A. lasiocarpa* and *P. engelmannii* will be increased, especially if the initial cutting removes a large proportion of *P. contorta*. The *A. lasiocarpa/V. scoparium* habitat type is not usually used by livestock but is medium-quality big game summer range. This habitat type also provides habitat for many birds and mammals. It occupies areas with the greatest potential for water yield [up to 15 inches (38 cm) of natural runoff annually] on the Gunnison National Forest. Small patch [3- to 5-acre (1.2- to 2.0-ha)] or strip [400-foot wide (122-m)] clearcuts result in greater forage production for big game [450 to 500 pounds per acre (504 to 560 kg/ha)] and larger increases in water available for streamflow than either shelterwood, group selection, or individual-tree selection cutting (Alexander 1977, 1986d; Alexander and Edminster 1980; Leaf 1975; Leaf and Alexander 1975; Regelin and Wallmo 1978; Wallmo et al. 1972). If larger openings are cut, slash should be left in place to create surface roughness needed to retain snowpack. Streamflow in these openings will be about 66% to 75% of the runoff in small patch or strip clearcuts.

Streamflow can be increased with partial cutting on north slopes, but the average increase may not be as great as with clearcutting in small patches or strips (Troendle and Meiman 1984). Because of the increase in tree reproduction, forage production begins to decline in about 15 to 20 years, and water production in 20 to 30 years. Therefore, new openings must be cut periodically to maintain increases in forage and water.

Abies lasiocarpa/Vaccinium myrtillus

Description.—*Abies lasiocarpa/Vaccinium myrtillus* is the most widespread habitat type in this series on the Gunnison National Forest. Here, it occurs in the upper montane and lower subalpine zones at lower elevations than occupied by the *A. lasiocarpa/Vaccinium scoparium* habitat type, although further to the south the replacement becomes more complete at all elevations. The *A. lasiocarpa/V. myrtillus* habitat type is represented by three stands. One stand is on Sargents Mesa on a gentle (3%) southeast-facing slope; another is near Marshall Pass on a gentle (5%) northeast-facing slope; and the third stand is just below Monarch Pass on a steep (31%) southwest-facing slope. One stand (231) originally was classified by Komarkova[3] as a late seral *Pinus contorta/V. myrtillus* community type successional to the *A. lasiocarpa/V. myrtillus* habitat type. Another stand (93) was originally classified by Komarkova[3] as a *P. contorta/V. myrtillus* habitat type, but there is no evidence that *P. contorta* is self-perpetuating in this stand. Soils in this habitat type are loamy (table 1).

Figure 32.—*Abies lasiocarpa/Vaccinium myrtillus* habitat type on Sargents Mesa, Cochetopa Hills. *V. myrtillus* is the principal undergrowth species. *Vaccinium scoparium* is absent.

The *A. lasiocarpa/V. myrtillus* habitat type is normally recognized by the almost constant presence and reproductive success of *Abies lasiocarpa*, and by the abundance and undergrowth dominance of *Vaccinium myrtillus* and near absence of *Vaccinium scoparium*. *Picea engelmannii* is usually present as a self-reproducing co-climax species (fig. 32). In two of the stands sampled (93 and 231) *A. lasiocarpa* was not present. This suggests

the possibility of either a *P. engelmannii/V. myrtillus* habitat type or an *A. lasiocarpa/V. myrtillus* habitat type, *P. engelmannii* phase. A *P. engelmannii/V. myrtillus* habitat type has been described in northern and southwestern New Mexico, and the Front Range and southern Colorado (DeVelice et al. 1986, Fitzhugh et al. 1987, Moir and Ludwig 1979, Radloff 1983). However, *A. lasiocarpa* was either a minor dominant or at least present in the stands sampled. Because the sampled stands on the Gunnison National Forest were small and the sample size limited, the absence of *A. lasiocarpa* may be an artifact of sampling; thus the occurrence of a *P. engelmannii/V. myrtillus* habitat type cannot be confirmed without additional sampling.

The overstory of most stands in this habitat type is dominated by *Picea engelmannii*, with *Abies lasiocarpa* as a codominant, although either species may be absent in individual plots sampled within stands. *P. contorta* is an important seral species and still dominates some of the stands in late stages of succession. However, the self-perpetuating species in these stands are *A. lasiocarpa* and *P. engelmannii. Populus tremuloides* is only an occasional seral species. In addition to *Vaccinum myrtillus* (28–70% cover), other important undergrowth species are *Juniperus communis, Ribes montigenum, Carex foenea, Festuca thurberi, Koeleria macrantha, Arnica cordifolia, Arnica latifolia, Pyrola* spp., *Solidago* spp., and *Thermopsis montana. Vaccinium scoparium, Carex geyeri*, and *Pedicularis racemosa* are absent or very inconspicuous.

The *A. lasiocarpa/V. myrtillus* habitat type, or others very similar to it, occur throughout the southern Rocky Mountain and Intermountain regions (Alexander et al. 1987, DeVelice et al. 1986, Fitzhugh et al. 1987, Hoffman,[5] Moir and Ludwig 1979, Youngblood and Mauk 1985). However, there is considerable variability in undergrowth composition and cover within this habitat type.

Management implications.—Timber productivity for the climax species varies considerably in the *A. lasiocarpa/V. myrtillus* habitat type, but can be higher than in the *A. lasiocarpa/Vaccinium scoparium* habitat type (Alexander 1967). Moreover, timber productivity may be relatively high for seral *P. contorta* in this habitat type. Undergrowth vegetation changes slowly after major disturbance, and competition is not severe between tree seedlings and undergrowth vegetation, except where cover of herbaceous dicots is high. *P.* engelmannii reproduction may be difficult to obtain on south slopes and other dry situations. There may be a manageable stand of advanced reproduction in much of this habitat type, especially in the late seral stages.

Cutting methods and growing stock levels are similar to those suggested for the *A. lasiocarpa/V. scoparium* habitat type (Alexander 1986a). Where there is an appreciable amount of either *P. contorta* or *P. tremuloides* in the stands, clearcutting or simulated shelterwood is likely to increase their representation in the new stand.

This habitat type provides summer forage for livestock and big game; but forage production is low, and there is little potential for increasing it by cutting timber. Natural runoff in the *A. lasiocarpa/V. myrtillus* habitat type usually is slightly less than in the *A. lasiocarpa/V. scoparium* habitat type, but can be increased significantly using the same cutting methods suggested for *A. lasiocarpa/V. scoparium* habitat type. The potential for developed and dispersed recreation is the highest in the *A. lasiocarpa* series.

Abies lasiocarpa/Juniperus communis

Description.—The *Abies lasiocarpa/Juniperus communis* habitat type was sampled in two successional stands. One stand (154), on the Perfecto Creek Road on a gentle (7%) northeast-facing slope, is a late seral *Populus tremuloides-Picea engelmannii/Juniperus communis* community type (Komarkova [3]). The other stand (155), near Perfecto Creek on a gentle (9%) east-facing slope, is a midseral *P. tremuloides-P. engelmannii/J. communis-Festuca idahoensis* plant community (Komarkova[3]). Soils in both stands are shallow, rocky, sandy loams (table 1).

This habitat type is normally recognized by the reproductive success of *Picea engelmannii* and *Abies lasiocarpa*; but, *A. lasiocarpa* was not present in the stands sampled, suggesting the possibility of a *P. engelmannii/J. communis* habitat type. Because the plots sampled are small and successional, and the sample size is limited, the absence of *A. lasiocarpa* may be an artifact of sampling. Although a *P. engelmannii/J. communis* habitat type has been identified in northwest Wyoming by Steele et al. (1983), this habitat type has not been previously identified in the National Forests adjacent to the Gunnison National Forest (Hess and Wasser;[2] Hoffman;[5] Hoffman and Alexander 1980, 1983). Moreover, stands dominated only by *P. engelmannii* are not common in Colorado. The occurrence on the Gunnison National Forest of a *P. engelmannii/J. communis* habitat type cannot be confirmed without additional sampling. Although the overstory in the sampled stands is presently dominated by *Populus tremuloides*, there is no evidence that it is self-perpetuating. *Pinus contorta* was absent in the stands sampled. The undergrowth is recognized by the abundance of *Juniperus communis* (5–12% cover) in the shrub layer, even though *Festuca idahoensis* has high coverage (30%) in one stand (fig. 33). Other undergrowth species with high cover are *Arctostaphylos adenotricha, Shepherdia canadensis, Carex geophila, Koeleria macrantha, Achillea lanulosa, Fragaria virginiana, Potentilla hippiana, Senecio* spp., and *Solidago multiradiata*.

This habitat type has not been reported previously in the central and southern Rocky Mountains (Alexander 1988). It occurs further north in central Idaho, northwestern Wyoming, and Utah (Mauk and Henderson 1984; Steele et al. 1981, 1983; Youngblood and Mauk 1985). The *A. lasiocarpa/J. communis* habitat type also occurs south of the Gunnison National Forest in northern Arizona and New Mexico (Moir and Ludwig 1979).

Management implications.—Timber productivity potential in the dry, rocky *A. lasiocarpa/J. communis* habitat type is low. Regeneration is more difficult to obtain than in the *A. lasiocarpa/Vaccinium* spp. habitat

types in this series. *Picea engelmannii* can be expected to dominate all stages of succession, with the exception of early stages which may be dominated by *Populus tremuloides*. Consequently there are fewer options available for managing *P. tremuloides*-dominated stands in this habitat type. Competition from *A. lasiocarpa* for dominance in climax stands is less common than in the *A. lasiocarpa/Vaccinium* spp.-dominated habitat types. These sites are very stable. In natural stands, regeneration is sporadic and limited to the moister sites. Consequently, standard silvicultural practices that remove all of the overstory in one operation are not likely to be successful in regenerating a new stand within an acceptable time frame. Even with partial cutting, regeneration will be slow and erratic. Forage production potential for livestock is low in climax stands, but may be moderate to high in early successional stands dominated by *P. tremuloides*, on sites with loamy soils and a high cover of palatable graminoids in the undergrowth. Big game may use the habitat type for both cover and forage, but most use will be related to proximity to other plant communities with higher forage production potential. Open stands on ridges may have potential as bighorn sheep transitional range if the open canopy can be maintained. Natural runoff in the *A. lasiocarpa/J. communis* habitat type may be relatively high [10 to 12 inches (25 to 30 cm)]; but, potential for increasing streamflow is low because timber harvesting options are limited.

Abies lasiocarpa/Arnica cordifolia

Description.—The *Abies lasiocarpa/Arnica cordifolia* habitat type is represented by two stands. One stand is near Rainbow Lake on a gentle (9%) northeast-facing slope. This stand is one of several scattered stands occurring in sheltered situations that are more moist than the *A. lasiocarpa/Vaccinium* spp.-dominated habitat types, but drier than the associated *A. lasiocarpa/Polemonium pulcherrimum* and *A. lasiocarpa/Senecio triangularis* habitat types. The second stand is a lower elevation, older, less disturbed representative of this habitat type. It is near Kebler Pass on a gentle (7%) northwest-facing slope. Soils in this habitat type are relatively deep loams (table 1).

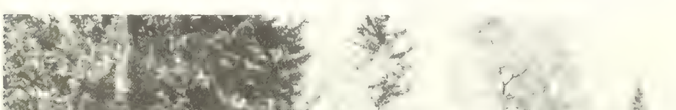

Figure 33.—*Abies lasiocarpa/Juniperus communis* habitat type on the Perfecto Creek road. Note late seral stage *Populus tremuloides* still persists in this stand. *Arctostaphylos adenotricha, Shepherdia canadensis*, and *Koeleria macrantha* are important undergrowth associates of *J. communis*.

Figure 34.—Abies lasiocarpa/Arnica cordifolia habitat type near Kebler Pass. *A. cordifolia, Aquilegia coerulea, Erigeron* spp., and *Fragaria virginiana* are the principal undergrowth species.

This habitat type is recognized by the overstory dominance of *Picea engelmannii*, the constant abundance of *Abies lasiocarpa* in both the overstory and tree reproduction, and the abundance of *Arnica cordifolia* in the undergrowth (6–10% cover) (fig. 34). *Pinus contorta* and *Populus tremuloides* were absent in the stands sampled. Major shrubs in the undergrowth are *Lonicera involucrata, Ribes inerme*, and *Ribes montigenum*. In addition to *A. cordifolia*, herbaceous species with high cover include *Carex geyeri, Aquilegia coerulea, Erigeron formosissimum, Fragaria virginiana, Osmorhiza depauperata, Pedicularis racemosa, Pseudocymopterus montanus*, and *Senecio intergerrimus*.

Hoffman and Alexander (1976) reported an *A. lasiocarpa/A. cordifolia* habitat type on the Bighorn National Forest in Wyoming that represented some of the oldest *Abies-Picea* stands in the Bighorn Mountains. Further north, Pfister et al. (1977) and Steele et al. (1981, 1983) reported this habitat type in Montana, east-central Idaho, and northwestern Wyoming. However, the composition of undergrowth in this northern *A. lasiocarpa/A. cordifolia* habitat type is different than that reported for

western Colorado. Moreover, the northern version of the habitat type often has *P. contorta* as a conspicuous seral species.

Management implications.—On the Gunnison National Forest, there does not appear to be any seral tree species in the *A. lasiocarpa/A. cordifolia* habitat type. Undergrowth vegetation does not appear to compete severely with tree seedlings after cutting. Timber productivity may be lower in this habitat type than in the *A. lasiocarpa/Vaccinium myrtillus* habitat type. Even- and uneven-aged cutting methods and growing stock levels—which benefit timber and water production, recreation, and esthetics—suggested for the *A. lasiocarpa/Vaccinium scoparium* habitat type are applicable here. Management with advanced reproduction is likely to result in a replacement stand predominantly of *A. lasiocarpa*, however. In older stands, some treatment of down material is necessary for future management. Younger stands provide some forage for livestock and big game, but older stands are used primarily for bedding grounds. The potential for increasing forage production by harvesting timber is not great in this habitat type.

Abies lasiocarpa/Senecio triangularis

Description.—The *Abies lasiocarpa/Senecio triangularis* habitat type was sampled in only one stand, but it has been reported elsewhere in Colorado under similar circumstances (Alexander 1987). The *A. lasiocarpa/S. triangularis* habitat type occurs occasionally on the Gunnison National Forest in small stands, in relatively wet sites, in valley bottoms, drainages, and in depressions at higher elevations. The sampled stand is in the Gothic Research Natural Area on a gentle (2%) south-facing slope. Soils in this habitat type are loams (table 1). Soils generally are well drained at the beginning of the growing season but remain at or near field capacity during the growing season.

This habitat type is recognized by the overstory dominance and reproductive success of *Abies lasiocarpa* and *Picea engelmannii*, and the dominance of the undergrowth by *Senecio triangularis* and/or *Streptopus fassettii*. *S. triangularis* is the most constant, but cover is fairly low (4%) in the sampled stand (fig. 35). *Pinus contorta* is rarely seen in this habitat type on the Gunnison National Forest, and *Populus tremuloides* is usually absent. The only shrubs present are *Lonicera involucrata* and *Vaccinium myrtillus*. Herbaceous species with high cover values include *Carex* spp., *Equisetum arvense*, *Pseudocymopterus montanus*, *S. triangularis*, and *S. fassettii*.

In Colorado, Hess and Alexander (1986) reported this habitat type on the Arapaho and Roosevelt National Forests. It has not been observed elsewhere in the Rocky Mountain and Intermountain regions (Alexander 1985, 1988). However, Cooper et al. (1987) and Steele et al. (1981, 1983) reported an *A. lasiocarpa/Streptopus amplexifolius* habitat type in northwestern Utah and southern Idaho that closely approximates the *A. lasiocarpa/S. triangularis* habitat type described here. Mauk and

Figure 35.—*Abies lasiocarpa/Senecio triangularis* habitat type near Gothic Natural area. *Equisetum arvense, Pseudocymopterus montanus*, and *Streptopus fassettii* are principal undergrowth associates of *S. triangularis*.

Henderson (1984) and Steele et al. (1983) reported a *P. engelmannii/Caltha leptosepala* habitat type in northern Utah, northwestern Wyoming, and southeastern Idaho that has many of the associated undergrowth species found in the *A. lasiocarpa/S. triangularis* habitat type.

Management implications.—Timber productivity in the *A. lasiocarpa/S. triangularis* habitat type is average to above average, but the high water table associated with the habitat type severely hampers any timber management activity, including road construction and maintenance. Road and trail costs are expected to be maximum in this habitat type. Moreover, the small area occupied by the habitat type limits its importance as a timber resource; conversely, the small stand size makes it easier to avoid. Clearcutting will cause the water table to rise to the ground surface and initially preclude establishment of tree species. Recovery after disturbance is extremely slow. Partial cutting increases the risk of blowdown. Forage production for livestock is moderately high, but the potential for trampling damage and soil compaction also is very high. The potential for increasing streamflow may be high, but management for water production is not a viable alternative because of the effect timber harvesting has on the water table and soil compaction. These stands are also subject to the special management prescriptions applied to riparian areas in

Forest Plans in the Rocky Mountain region. The principal value of the *A. lasiocarpa/S. triangularis* habitat type is for watershed and streamside protection, big game summer range, and habitat for birds and small mammals. However, trampling damage by big game can also cause soil compaction and subsequent erosion.

Abies lasiocarpa/Polemonium pulcherrimum

Description.—The *Abies lasiocarpa/Polemonium pulcherrimum* is a high-elevation habitat type. It occurs on sites within the range of the *A. lasiocarpa/Vaccinium myrtillus* habitat type, except that it usually occurs at higher elevations and on moister sites. This habitat type is drier than the *A. lasiocarpa/Senecio triangularis* habitat type and wetter than the *A. lasiocarpa/Vaccinium* spp.-dominated habitat types. This habitat type is represented by two stands, one just north of Schofield Pass on a gentle (9%) northwest-facing slope. The second stand sampled is on Alpine Plateau on a gentle (3%) northwest-facing slope. This habitat type is recognized as tentative, because there is some evidence to suggest that one stand (215) may be a *P. pulcherrimum* phase of the *A. lasiocarpa/Vaccinium myrtillus* habitat type; and the other stand (180) may be an *A. lasiocarpa/Ribes* spp.-dominated habitat type. Until additional sampling either confirms or refutes it, an *A. lasiocarpa/P. pulcherrimum* habitat type is recognized. Soils in the stands sampled are sandy loams (table 1).

The *A. lasiocarpa/P. pulcherrimum* habitat type is recognized by the overstory dominance and reproductive success of *Abies lasiocarpa* and *Picea engelmannii*, and the abundance of *Polemonium pulcherrimum* (8% cover in both stands) in the undergrowth (fig. 36). *Pinus contorta* and *Populus tremuloides* were absent from the stands sampled. Shrubs include *Ribes coloradense* (4% cover, stand 215), *Ribes inerme* (8% cover, stand 180), and *Vaccinium myrtillus* (6% cover, stand 215). The herbaceous undergrowth is dominated by *P. pulcherrimum*, *Arnica cordifolia*, *Arnica latifolia*, *Caltha leptosepala*, *Cardamine cordifolia*, *Lupinus argenteus* , *Mertensia ciliata*, *Mitella pentandra*, and *Pryola* spp.

Figure 36.—*Abies lasiocarpa/Polemonium pulcherrimum* habitat type north of Schofield Pass. *Caltha leptosepala* and *Arnica cordifolia* are undergrowth associates with high cover.

The *A. lasiocarpa/P. pulcherrimum* habitat type has not been identified in Colorado (Alexander 1987) or elsewhere in the Rocky Mountain and Intermountain regions (Alexander 1985, 1988). However, in northern New Mexico and southern Colorado, DeVelice et al. (1986) described similar stands as a *Picea engelmannii/Vaccinium myrtillus* habitat type, *P. pulcherrimum* phase, in which *Abies lasiocarpa* often was a codominant. This further suggests that stands with high cover of *P. pulcherrimum* may belong to a phase of either an *A. lasiocarpa/V. myrtillus* or a *P. engelmannii/V. myrtillus* habitat type.

Management implications.—Timber productivity in the *A. lasiocarpa/P. pulcherrimum* habitat type is comparable to the *A. lasiocarpa/Vaccinium myrtillus* habitat type, but this habitat type occurs on colder and moister sites. Reproduction may be slow to establish, but undergrowth vegetation does not compete severely with tree seedlings after cutting. Cutting practices and growing stock levels—which benefit timber and water production, recreation, and esthetics—suggested for the *A. lasiocarpa/Vaccinium scoparium* habitat type are applicable here. Forage production is low in this habitat type, with little potential for increasing it by cuttting timber. Big game use in this habitat is primarily for resting and hiding cover.

Abies lasiocarpa/Calamagrostis canadensis

Description.—This minor habitat type, represented by one stand in Spring Creek Canyon, occurs in small stands on the Gunnison National Forest; however, it has been recognized elsewhere in Colorado. The *Abies lasiocarpa/Calamagrostis canadensis* habitat type has the coldest and wettest environment in the *A. lasiocarpa* series because of high groundwater levels and cold air drainage from surrounding uplands. It occurs in bottomlands on benches adjacent to streams. The sampled stand is on a gentle (5%) south-facing slope. Despite the cold, wet environment, the soils are primarily mineral, with a high organic content, and are poorly drained (table 1).

This habitat type is usually distinguished by an open canopy dominated by *Abies lasiocarpa* and *Picea engelmannii*. However, in the sampled stand, *A. lasiocarpa* was absent. *Populus tremuloides* may be a seral species in some stands, but *Pinus contorta* is usually absent. The undergrowth is dominated by *Calamagrostis canadensis* (55% cover) (fig. 37). Shrub associates include *Lonicera involucrata*, *Rosa woodsii*, *Salix glauca*, and *Swida sericea*. Important graminoids are *C. canadensis*, *Carex geyeri*, *Carex utriculata*, and *Poa leptocoma*. *Equisetum arvense*, *Heracleum sphondylium*, and *Smilacina stellata* are the major forb associates.

An *A. lasiocarpa/C. canadensis* habitat type has been reported on the Arapaho and Roosevelt National Forests by Hess and Alexander (1986), but it has a richer mixture of undergrowth species. Further north, an *A. lasiocarpa/C. canadensis* habitat type with ecological and

floristic similarity, has been reported in northern Idaho by Cooper et al. (1987), in central Idaho by Steele et al. (1981), in Montana by Pfister et al. (1977), in southeastern Idaho and northwestern Wyoming by Steele et al. (1983), and in northern Utah by Mauk and Henderson (1984).

Management implications.—The management implications for this habitat type are similar to the *A. lasiocarpa/Senecio triangularis* habitat type. However, the *A. lasiocarpa/C. canadensis* habitat type is even more difficult to regenerate, especially if it is clearcut, because of intense competition from undergrowth species, saturated soils, and colder sites. Because of the high water table, partial cutting is likely to result in heavy windthrow. Clearcutting initially causes the water table to rise to the ground surface; therefore, this habitat type should be avoided for road, trail, or recreational development because of saturated soils and the potential for soil compaction and mass movement. The *A. lasiocarpa/C. canadensis* habitat type may have moderately high potential for livestock forage production, but grazing should be avoided when soils are saturated because of potential for trampling damage. The value of this habitat type is for watershed protection and wildlife habitat; however, trampling damage by big game also can cause soil compaction and subsequent erosion.

Abies lasiocarpa/Moss

Description.—The *Abies lasiocarpa*/Moss habitat type generally occurs on zonal surfaces at higher elevations in the study area. This cold, moderately dry habitat type was sampled in three stands on Mexican Joe Gulch, Alpine Plateau, and North Fork Valley. These stands occur on gentle (3–5%) north- to east-facing slopes. Soils are shallow sandy loams (table 1).

This cold and dry habitat type is recognized by the overstory dominance of *Abies lasiocarpa* and *Picea engelmannii*, although two of the stands sampled did not contain *A. lasiocarpa*. Whether the absence of *A. lasiocarpa* is an artifact of sampling or an indication of a possible *P. engelmannii*/Moss habitat type cannot be confirmed without additional sampling. *Pinus contorta* was rarely seen in this habitat type in the Gunnison National Forest, but *Populus tremuloides* was an occasional overstory associate. The diagnostic feature of this habitat type is a sparse undergrowth of shrubs, graminoids, and forbs; moss spp. cover is evident because of the scarcity of other undergrowth. In some stands, lichen spp. cover may be higher than cover by moss spp. (fig. 38).

Figure 37.—*Abies lasiocarpa/Calamagrostis canadensis* habitat type, Spring Creek Canyon. Important undergrowth associates include *Lonicera involucrata, Swida sericea*, and *Equisetum arvense*.

Figure 38.—*Abies lasiocarpa*/Moss habitat type high in the North Fork Valley south of Lake City. Note the sparse undergrowth.

This habitat type has been described in northern New Mexico by DeVelice et al. (1986) and on the Medicine Bow National Forest in southern Wyoming by Alexander et al. (1986). The *A. lasiocarpa*/Moss habitat type has not been reported elsewhere in the Rocky Mountain or Intermountain regions (Alexander 1985, 1988), but a *P. engelmannii*/Moss habitat type with similar characteristics was reported from northern New Mexico by Alexander et al. (1987), Fitzhugh et al. (1987), and Moir and Ludwig (1979), and in the Pike National Forest in the Colorado Front Range (Radloff 1983). In the Southwest, *A. lasiocarpa* may occur as a minor dominant in the *P. engelmannii*/Moss habitat type; but *P. engelmannii* also may occur in pure stands at higher elevations [above 11,500 feet (3,505 m)], a circumstance not frequently encountered in the central Rocky Mountains, where both *P. engelmannii* and *A. lasiocarpa* normally form the timberline forests.

Management implications.—Timber productivity in the *A. lasiocarpa*/Moss habitat type is very low because growth is slow. The potential for improvement also is low because of poor site quality. Regeneration, although slow to establish, is likely to be ultimately successful after either clearcutting in small openings or partial cutting, because there is little undergrowth to compete with tree seedlings. Until more information is available, cutting methods suggested for perpetuating the *A. lasiocarpa/ Vaccinium scoparium* habitat type probably are applicable to this habitat type, although regeneration may be more difficult to obtain following clearcutting. Livestock forage production is low, and there is little potential for improvement. Big game summer use is moderate, large-

ly as cover for deer and elk that feed in adjacent habitat types. Small game and birds use these stands, and they appear to be good habitat for tree owls. Natural runoff probably is equal to the *A. lasiocarpa/V. scoparium* habitat type. Whether streamflow in the *A. lasiocarpa*/Moss habitat type can be increased by the cutting methods suggested for the *A. lasiocarpa/V. scoparium* habitat type is unknown.

KEY TO FOREST HABITAT TYPES

The following key will enable users to identify the habitat type of most forested and woodland stands on the Gunnison National Forest. The key will work best on climax or late seral stands. Caution must be exercised when attempting to project stand succession forward in early seral or midseral stands.

1. Coniferous trees dominant and reproducing; deciduous trees may be present but are rare or not reproducing sufficiently to become dominant, or are being replaced by coniferous trees .... (2)
2. *Juniperus osteosperma* dominant and reproducing; other conifers absent or not dominant; undergrowth dominated by shrubs *Symphoricarpos oreophilus* and *Mahonia fremonti*. Lowest elevations within forested zones, on sedimentary soils ..... *JUNIPERUS OSTEOSPERMA/SYMPHORICARPOS OREOPHILUS* H.T.
2. *Juniperus osteosperma* absent or not dominant; higher elevations, on a variety of soils .... (3)
3. *Pinus ponderosa* dominant and reproducing on warm dry sites; other conifers absent or, if present, not dominant or reproducing successfully .... (4)
4. *Festuca idahoensis* present in significant amounts, but undergrowth may be dominated by *Artemisia tridentata* because of past grazing use; *Muhlenbergia montana* absent .... *PINUS PONDEROSA/FESTUCA IDAHOENSIS* H.T.
4. *Festuca idahoensis* absent or sparse. Undergrowth dominated by *Festuca arizonica*; *Muhlenbergia montana* may have high cover; shrubs and forbs are sparse ... *PINUS PONDEROSA/FESTUCA ARIZONICA* H.T.
3. *Pinus ponderosa* absent, rare, or clearly seral; cooler and/or moister sites; other conifers present and reproducing successfully .... (5)
5. *Pseudotsuga menziesii* climax and reproducing successfully; other conifers may be present, but not dominant or reproducing .... (6)
6. Undergrowth dominated by shrubs; graminoids present but not dominant .... (7)
7. *Purshia tridentata* usually dominates the undergrowth; *Artemisia tridentata* may be dominant in some stands because of past grazing use; *Arctostaphylos adenotricha* and *Juniperus communis* usually present and cover may be high, but not dominant; *Symphoricarpos oreophilus, Jamesia americana* and *Paxistima myrsinites* absent or rare .... *PSEUDOTSUGA MENZIESII/PURSHIA TRIDENTATA* H.T.
7. *Purshia tridentata* and *Artemisia tridentata* absent or sparse. *Symphoricarpos orephilus, Jamesia americana* or *Paxistima myrsinites* may be abundant .... (8)
8. *Symphoricarpos oreophilus* dominant in the undergrowth. *Jamesia americana* and *Paxistima myrsinites* absent or sparse; *Mahonia repens* also absent or sparse .... *PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS* H.T.
8. *Symphoricarpos oreophilus* absent or sparse; *Jamesia americana* or *Paxistima myrsinites* may be abundant (9)
9. *Jamesia americana* dominates the undergrowth; *Paxistima myrsinites* absent or sparse; *Mahonia repens* and *Arctostaphylos adenotricha* present but not dominant .... *PSEUDOTSUGA MENZIESII/JAMESIA AMERICANA* H.T.
9. *Jamesia americana* absent or sparse; *Paxistima myrsinites* dominates the undergrowth; *Holodiscus dumosus, Mahonia repens*, and *Ribes inerme* may be present but not dominant; *Carex geyeri* may be conspicuous . ... *PSEUDOTSUGA MENZIESII/PAXISTIMA MYRSINITES* H.T.
6. Undergrowth dominated by graminoids .... (10)
10. *Carex geyeri* dominates the undergrowth; *Symphoricarpos oreophilus* may have high cover, but not dominant. *Mahonia repens, Rosa woodsii*, and *Festuca idahoensis* also may be present .... *PSEUDOTSUGA MENZIESII/CAREX GEYERI* H.T.
10. *Carex geyeri* and *Koeleria macrantha* may be present but not dominant; *Festuca idahoensis* dominates the undergrowth; shrubs absent or sparse ...... *PSEUDOTSUGA MENZIESII/FESTUCA IDAHOENSIS* H.T.
5. *Pseudotsuga menziesii* may be present, and reproducing but not dominant at climax; other conifers dominate both moist and dry sites .... (11)
11. *Picea pungens* climax and reproducing well; riparian or other cool, moist sites .... (12)
12. Undergrowth dominated by shrubs characteristic of streamside and riparian situations. *Amelanchier alnifolia* is dominant; *Prunus virginiana, Ribes inerme, Rosa woodsii, Swida sericea*, and *Symphoricarpos oreophilus* are present; graminoids present but not dominant .... *PICEA PUNGENS/AMELANCHIER ALNIFOLIA* H.T.
12. Shrubs absent or present; undergrowth dominated by graminoids; *Festuca arizonica* is dominant; *Danthonia parryi* may have high cover; *Koeleria macrantha* and *Muhlenbergia montana* usually present .... *PICEA PUNGENS/FESTUCA ARIZONICA* H.T.

11. *Picea pungens* absent or sparse; other conifers present and reproducing vigorously; on exposed, well-drained or dry, rocky sites .... (13)
13. *Pinus flexilis* present and reproducing on dry, rocky sites; other conifers absent or not reproducing well; shrubs and graminoids present but not dominant; *Ciliaria austromontana* dominates the undergrowth .... *PINUS FLEXILIS/CILIARIA AUSTROMONTANA* H.T.
13. *Pinus flexilis* absent or sparse, other conifers present and self-reproducing .... (14)
14. *Pinus contorta* dominant and climax; other conifers may be present but not reproducing well enough to replace *Pinus contorta* .... (15)
15. Shrubs dominate the undergrowth. Graminoids not common or not dominant .... (16)
16. *Juniperus communis* dominates the sparse undergrowth; *Arctostaphylos adenotricha* may be codominant; *Vaccinium* spp. absent or sparse; herbaceous layer depauperate; lower elevation colluvial benches .... *PINUS CONTORTA/JUNIPERUS COMMUNIS* H.T.
16. *Juniperus communis* absent or sparse; undergrowth depauperate, dominated by *Vaccinium scoparium*; higher elevation ridges and slopes .... *PINUS CONTORTA/VACCINIUM SCOPARIUM* H.T.
15. Shrubs poorly represented in the undergrowth; *Carex geyeri* dominates the undergrowth; other graminoids present but not dominant; *Arnica cordifolia* and *Fragaria virginiana* may be conspicuous .... *PINUS CONTORTA/CAREX GEYERI* H.T.
14. *Pinus contorta* absent or not reproducing vigorously, not climax; other conifers reproducing vigorously and will replace *Pinus contorta* .... (17)
17. *Abies lasiocarpa* and *Picea engelmannii* usually present and reproducing successfully, but either species may be absent in any given stand; *Picea engelmannii* may dominate both overstory and understory; *Populus tremuloides* and *Pinus contorta* may be present and dominating the overstory, but not reproducing well, not climax. *Pinus aristata* absent .... (18)
18. Shrubs dominate the undergrowth; graminoids and forbs, mosses and lichen may be present but not dominant .... (19)
19. *Juniperus communis* dominates the undergrowth; *Arctostaphylos adenotricha* or *Shepherdia canadensis* may be present but not dominant; *Vaccinium* species absent .... *ABIES LASIOCARPA/JUNIPERUS COMMUNIS* H.T.
19. *Juniperus communis* absent or sparse; undergrowth dominated by *Vaccinium* spp. .... (20)
20. Undergrowth dominated by *Vaccinium scoparium; V. myrtillus* may be present but not dominant .... *ABIES LASIOCARPA/VACCINIUM SCOPARIUM* H.T.
20. *Vaccinium scoparium* absent or sparse; undergrowth dominated by *Vaccinium myrtillus* .... *ABIES LASIOCARPA/VACCINIUM MYRTILLUS* H.T.
18. Shrubs generally absent or sparse, or if present not dominant; undergrowth dominated by graminoids, forbs or moss and lichen .... (21)
21. Undergrowth dominated by graminoids; forbs, mosses and lichen may be present but not dominant (22)
22. *Carex geyeri* abundant, dominates the undergrowth; *Calamagrostis canadensis* may be present, but not dominant .... *ABIES LASIOCARPA/CAREX GEYERI* H.T.
22. *Carex geyeri* sparse; undergrowth dominated by *Calamagrostis canadensis; Swida sericea* and *Equisetum arvense* may have significant cover .... *ABIES LASIOCARPA/CALAMAGROSTIS CANADENSIS* H.T.
21. Graminoids present but not dominant. Undergrowth dominated by forbs or mosses or lichens .... (23)
23. Undergrowth dominated by forbs; mosses and lichen may be present but not dominant .... (24)
24. *Arnica cordifolia* abundant and dominant; *Erigeron* spp. and *Osmorhiza depauperata* may have significant cover but are not dominant .... *ABIES LASIOCARPA/ARNICA CORDIFOLIA* H.T.
24. *Arnica cordifolia* present but not dominant .... (25)
25. *Polemonium pulcherrimum* abundant and dominant; *Caltha leptosepala* may have high cover but not abundant in all stands .... *ABIES LASIOCARPA/POLEMONIUM PULCHERRIMUM* H.T.
25. *Polemonium pulcherrimum* absent or sparse; *Senecio triangularis* present but cover varies; coverage of *Equisetum arvense* and *Streptopus fassettii* may be high .... *ABIES LASIOCARPA/SENECIO TRIANGULARIS* H.T.
23. Undergrowth dominated by mosses and/or lichens; forbs sparse, not dominant .... *ABIES LASIOCARPA/MOSS* H.T.
17. *Abies lasiocarpa* absent or sparse, *Picea engelmannii* may be present and reproducing, but not dominant; *Pinus contorta* and *Populus tremuloides* absent or sparse. *Pinus aristata* dominant, reproducing, and climax (26)
26. Shrubs dominate the undergrowth; graminoids and forbs present but not dominant. *Juniperus communis* dominant; *Rosa woodsii* may have abundant cover .... *PINUS ARISTATA/JUNIPERUS COMMUNIS* H.T.
26. Shrubs usually absent or sparse, not dominant; undergrowth dominated by graminoids; forbs present but also sparse .... (27)
27. *Festuca arizonica* dominates the undergrowth; *Muhlenbergia montana* may be a codominant .... *PINUS ARISTATA/FESTUCA ARIZONICA* H.T.
27. *Festuca arizonica* and *Muhlenbergia montana* absent or sparse; undergrowth dominated by *Festuca thurberi* .... *PINUS ARISTATA/FESTUCA THURBERI* H.T.

1. Coniferous trees absent or minor, not reproducing; deciduous trees present and reproducing ....(28)
28. *Quercus gambelii* present and reproducing successfully; conifers and *Populus tremuloides* may be present but not dominant ....(29)
29. Undergrowth dominated by the tall shrub *Amelanchier alnifolia; Prunus virginiana* and *Symphoricarpos oreophilus* present but not dominant; graminoids and forbs may also be present ....*QUERCUS GAMBELII/AMELANCHIER ALNIFOLIA* H.T.
29. *Amelanchier alnifolia* absent or sparse; undergrowth dominated by the tall shrub *Prunus virginiana; Carex geyeri* may be present but not dominant ....*QUERCUS GAMBELII/PRUNUS VIGINIANA* H.T.
28. *Quercus gamebelii* absent or not reproducing successfully; other deciduous trees present and reproducing (30)
30. *Populus angustifolia* present and reproducing successfully; conifers and *Populus tremuloides* may be present but not dominant; *Alnus incana, Swida sericea,* and *Salix* spp. well represented ....*POPULUS ANGUSTIFOLIA/ALNUS INCANA-SWIDA SERICEA* H.T.
30. *Populus angustifolia* and *Salix* spp. absent or poorly represented; *Populus tremuloides* present and reproducing successfully; conifers and other deciduous trees may be present but not dominant ....(31)
31. Undergrowth dominated by shrubs; graminoid and forb layers form a rich mixture but are not dominant (32)
32. Undergrowth dominated by tall or medium shrubs; *Amelanchier alnifolia* and *Prunus virginiana*, or *Symphoricarpos oreophilus* may be important ....(33)
33. Undergrowth dominated by *Amelanchier alnifolia* and *Prunus virginiana; Symphoricarpos oreophilus* may be present but not dominant ....*POPULUS TREMULOIDES/AMELANCHIER ALNIFOLIA-PRUNUS VIRGINIANA* H.T.
33. *Amelanchier alnifolia* and *Prunus virginiana* present but not dominant; undergrowth dominated by the medium shrub *Symphoricarpos oreophilus*; cover of low shrub *Mahonia repens* may be high ....*POPULUS TREMULOIDES/SYMPHORICARPOS OREOPHILUS* H.T.
32. Undergrowth dominated by low shrubs; sparse; *Arctostaphylos adenotricha* present and indicative of this dry site ....*POPULUS TREMULOIDES/ARCTOSTAPHYLOS ADENOTRICHA* H.T.
31. Undergrowth dominated by graminoids or forbs; shrubs present but not dominant ....(34)
34. Undergrowth dominated by graminoids ....(35)
35. *Festuca arizonica* dominates the undergrowth; *Festuca thurberi, Muhlenbergia montana,* and *Carex geyeri* present but not dominant ....*POPULUS TREMULOIDES/FESTUCA ARIZONICA* H.T.
35. *Festuca thurberi* dominates the undergrowth; *Festuca arizonica* and *Muhlenbergia montana* absent or sparse; *Arctostaphylos uva-ursi* and *Carex hoodii* may have significant cover ....*POPULUS TREMULOIDES*/FESTUCA THURBERI H.T.
34. Undergrowth dominated by forbs; shrubs and graminoids contribute to a rich mixture in the undergrowth but are not dominant ....(36)
36. Undergrowth dominated by tall forbs; *Thalictrum fendleri* usually present and dominant; *Lupinus argenteus, Lathyrus leucanthus, Ligusticum* spp. and *Polemonium pulcherrimum* may have significant cover ....*POPULUS TREMULOIDES/THALICTRUM FENDLERI* H.T.
36. *Thalictrum fendleri* and other tall forbs may be present but not dominant; *Pteridium aquilinum* dominates the undergrowth ....*POPULUS TREMULOIDES/PTERIDIUM AQUILINUM* H.T.

The distribution and successional status of tree species in relation to habitat type are shown in table 2.

DISCUSSION

VALIDITY OF HABITAT TYPE CLASSIFICATION

The practical value of the habitat type classifications has only begun to be realized as it relates to vegetation mapping, tree growth, tree susceptibility to diseases, and production of browse species for game animals. It also provides a framework within which to relate additional basic or applied biological studies (Daubenmire 1961, 1973, 1976).

The classification system, while using vegetation as the indicator of site potentials, combines available related information on soil and climate. This approach also takes a holistic view of units of land area. The older the stands observed, the more closely they approximate the potential (climax or near climax) of the landscape units studied (Daubenmire 1976).

The classification of forested habitat types recognizes climax tree species in an area; these are given primary consideration, and important seral species are noted. In this study, the major vegetation zones are dominated by *Pseudotsuga menziesii, Populus tremuloides, Pinus contorta,* and *Abies lasiocarpa* and *Picea engelmannii.* Undergrowth vegetation then is used to indicate habitat types within the forested portion of the zone named for a given tree species.

VERTICAL ZONATION OF FOREST TREE SPECIES

The most conspicuous forest distribution patterns in the study area are related to environmental changes associated with changes in elevation. For example, as elevation increases, temperature decreases and moisture increases. While, in general, the upper and lower eleva-

Table 2.—The ecological role of tree species in habitat types on the Gunnison National Forest.
C = major climax; c = minor climax; S = major seral species; s = minor seral species; o = occasional species

Habitat type \ Species	*Juniperus osteosperma*	*Quercus gambelii*	*Pinus ponderosa*	*Picea pungens*	*Pseudotsuga menziesii*	*Populus angustifolia*	*Salix amygdaloides*	*Populus tremuloides*	*Pinus contorta*	*Pinus flexilis*	*Picea engelmannii*	*Abies lasiocarpa*	*Pinus aristata*
Juniperus osteosperma/Symphoricarpos oreophilus	C	•	•	•	•	•	•	•	•	•	•	•	•
Quercus gambelii/Amelanchier alnifolia	•	C	•	•	•	•	o	•	•	•	•	•	•
Quercus gambelii/Prunus virginiana	•	C	•	•	•	•	•	•	•	•	•	•	•
Pinus ponderosa/Festuca arizonica	•	•	C	•	s	•	•	•	•	•	•	•	o
Pinus ponderosa/Festuca idahoensis	•	•	C	•	•	•	•	•	•	•	•	•	•
Picea pungens/Festuca arizonica	•	•	•	C	•	•	•	•	•	•	•	•	o
Picea pungens/Amelanchier alnifolia	•	•	o	C	s	•	•	o	•	•	•	•	•
Pseudotsuga menziesii/Paxistima myrsinites	•	•	•	•	C	•	•	•	•	•	•	•	•
Pseudotsuga menziesii/Purshia tridentata	•	•	S	•	C	•	•	S	S	•	•	•	•
Pseudotsuga menziesii/Symphoricarpos oreophilus	•	•	•	•	C	•	•	•	•	•	o	•	•
Pseudotsuga menziesii/Carex geyeri	•	•	c	o	C	•	•	s	•	•	•	•	•
Pseudotsuga menziesii/Festuca idahoensis	•	•	•	•	C	•	•	•	•	•	•	•	•
Pseudotsuga menziesii/Jamesia americana	•	•	•	•	C	s	•	•	S	s	•	•	•
Populus angustifolia/Alnus incana-Swida sericea	•	•	•	•	•	C	C	•	•	•	•	•	•
Populus tremuloides/Arctostaphylos adenotricha	•	•	•	•	•	•	•	C	•	•	•	•	•
Populus tremuloides/Festuca arizonica	•	•	•	•	•	•	•	C	•	•	•	•	•
Populus tremuloides/Festuca thurberi	•	•	•	•	•	•	•	C	•	•	•	•	o
Populus tremuloides/Symphoricarpos oreophilus	•	•	•	•	•	•	•	C	•	•	•	o	•
Populus tremuloides/Amelanchier alnifolia-Prunus virginiana	•	•	•	•	•	o	•	C	•	•	•	•	•
Populus tremuloides/Pteridium aquilinum	•	•	•	•	•	•	•	C	•	•	•	•	•
Populus tremuloides/Thalictrum fendleri	•	•	•	•	•	•	•	•	•	•	•	•	•
Pinus contorta/Juniperus communis	•	•	•	•	s	•	•	C	C	•	o	•	•
Pinus contorta/Carex geyeri	•	•	•	•	•	•	•	•	C	•	o	•	•
Pinus contorta/Vaccinium scoparium	•	•	•	•	•	•	•	•	C	•	o	•	•
Pinus flexilis/Ciliaria austromontana	•	•	•	•	o	•	•	•	•	C	•	•	•
Pinus aristata/Festuca arizonica	•	•	•	•	•	•	•	o	•	o	•	•	C
Pinus aristata/Juniperus communis	•	•	•	•	•	•	•	s	•	S	o	•	C
Pinus aristata/Festuca thurberi	•	•	•	•	•	•	•	•	•	•	o	•	C
Abies lasiocarpa/Carex geyeri	•	•	•	•	o	•	•	S	S	•	C	C	•
Abies lasiocarpa/Vaccinium scoparium	•	•	•	•	•	•	•	s	s	•	C	C	•
Abies lasiocarpa/Vaccinium myrtillus	•	•	•	•	•	•	•	s	S	•	C	C	•
Abies lasiocarpa/Juniperus communis	•	•	•	•	•	•	•	S	•	•	C	C	•
Abies lasiocarpa/Arnica cordifolia	•	•	•	•	•	•	•	•	•	•	C	C	•
Abies lasiocarpa/Senecio triangularis	•	•	•	•	•	•	•	•	•	•	C	C	•
Abies lasiocarpa/Polemonium pulcherrimum	•	•	•	•	•	•	•	•	•	•	C	C	•
Abies lasiocarpa/Calamagrostis canadensis	•	•	•	•	•	•	•	•	•	•	C	C	•
*Abies lasiocarpa/*Moss	•	•	•	•	•	•	•	s	•	•	C	C	•

tional limits of forest vegetation in the study area increases from north to south as climate becomes drier and more continental, the most significant variations in vegetational zonation are in response to local topography and climate. The different forested elevational zones support very different plant associations, ranging from treeline vegetation of the upper subalpine forest zone through closed-canopy forests of the subalpine and montane zone to woodlands and shrublands at the lower limits of forests. Also included are grassland parks on mountain ridges within the forested zones.

Within each elevational zone, two kinds of plant associations were distinguished: (1) zonal, which reflect the local climate and consist of relatively undisturbed stands; and (2) azonal, which are controlled by biotic or abiotic environmental factors and/or persistent disturbance factors, such as soils, grazing, and wind. Except for temporal implications, the forest habitat types that are zonal plant associations generally are climatic climaxes, while the azonal plant associations are edaphic, topographic, or topoedaphic climaxes or disclimaxes. Elevational zones are recognized on the basis of the differences in landforms and vegetation between them. In general, the forest stands in the subalpine zones have a considerably higher percentage of climax stands than the montane and woodland zones, because disturbance usually is greater at lower than higher elevations. Azonal plant associations may overlap elevational zones. For example, in the Gunnison National Forest, *Pinus contorta* is a widely distributed tree; several *P. contorta*-dominated plant associations occur in the upper and lower subalpine zones, and in the upper montane zone.

In both zonal and azonal plant associations, the maturity of forest vegetation is indicated by a balanced distribution of tree sizes, ranging from seedlings to very old trees. Mature zonal forest stands persist for long periods of time in the absence of catastrophic disturbance. Azonal forest stands persist as long as the disturbance or environmental factor that controls their stability persists.

The uppermost forested elevational zone in the study area is the upper subalpine zone that occurs from 10,500 feet (3,200 m) to timberline at about 11,500 feet (3,505 m). *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus aristata* are the most common treeline species. These are also the dominant climax species throughout the entire upper subalpine zone, with *Pinus contorta* and *Pinus flexilis* forming open-grown plant associations. Relatively extensive mountain grasslands dominated by *Festuca thurberi*, *Danthonia intermedia*, and *Deschampsia cespitosa* also occur in the zone. Riparian sites may be shrublands, dominated by *Salix* spp.; grasslands, with *D. cespitosa*; or wetlands, with *Carex* spp.

The lower subalpine zone occurs at elevations of 9,500 to 10,500 feet (2,895 to 3,200 m). *P. engelmannii*-, *A. lasiocarpa*-, *P. contorta*-, and *Populus tremuloides*-dominated stands occur extensively throughout the zone. *P. aristata*- and *P. flexilis*-dominated stands have only local distribution. *A. lasiocarpa* usually is subordinate to *P. engelmannii* in the overstory and may be dominant, subordinate, or absent in the understory. *P. tremuloides* generally dominates stands that are successional to conifers but is climax under certain topoedaphic circumstances. *P. contorta* dominates large areas recovering from disturbance. It may be either a long-lived seral or a climax if there is no evidence of replacement. The latter circumstance may be due to a lack of seed source from competing species or topoedaphic conditions that preclude the establishment of other species.

The upper montane zone lies between 8,500 and 9,500 feet (2,590 and 2,895 m) elevation. The most common trees are *P. tremuloides*, *Pseudotsuga menziesii*, and *P. contorta*. *Pinus ponderosa* is an infrequent dominant but may occur as a seral species. *P. tremuloides* and *P. contorta* dominate primarily long-lived seral stands, but *P. contorta* may also be a topoedaphic climax. *P. menziesii* is the dominant climax species. *Picea pungens* may be a dominant species in riparian habitats or, occasionally, on dry uplands. *A. lasiocarpa* and *P. engelmannii* may occur along streams and in cold, moist valley bottoms.

The lower montane zone, between 7,500 and 8,500 feet (2,286 and 2,590 m), normally is dominated by *P. ponderosa* and *P. menziesii*, but *P. ponderosa* has only limited distribution in the Gunnison National Forest. *P. contorta* may occur at the upper limits of the zone, usually as a long-lived seral. *P. tremuloides* frequently forms climax stands. *P. pungens* may be climax on upland sites but more often is confined to bottomlands and rocky sites. *Quercus gambelii* may occur as a climax at the lower limits of this zone.

The woodland zone occurs at elevations of 6,500 to 7,800 feet (1,981 to 2,590 m). *P. tremuloides* and *Q. gambelii* plant associations commonly occur as climaxes. *Juniperus osteosperma* and/or *Pinus edulis* generally are rare. *Populus angustifolia* and *P. pungens* dominate riparian forests. *P. menziesii* and *P. ponderosa* also are rare.

VEGETATION CLASSIFICATION AND RECOVERY AFTER DISTURBANCE

Emphasis of this study was on the identification of climax plant associations and their landforms. A few successional communities were sampled to determine which species might identify successional status. These species then could be used to indicate the degree of disturbance of the presumably climax plant communities. In most of the study area, climax plant communities are relatively rare in azonal habitats. During the last 100 years, mining, railroads, and other disturbances directly affected only small portions of the Gunnison National Forest. However, the associated effects of disturbances, such as grazing, fires, disease, insects, and logging, affected almost the entire forested area, particularly at lower elevations. The relatively high disturbance level in the study area enabled many disturbance-induced plant species to become established in the undergrowth of climax forests. The ubiquity of these successional plant species is one of the reasons why it was very difficult to develop an objective classification based on sampled stands that would correlate with the habitat type classification presented here. The classification was produced primarily on the basis of a subjective comparison of the species composition of the sampled stands with the species composition of similar stands sampled elsewhere.

Many of the major forest habitat types sampled on the Gunnison National Forest are represented by a single stand. This also contributed to the difficulty of developing an objective classification, because the full range of the species composition and cover in each habitat type was not known. This information was missing not only for the Gunnison National Forest habitat types, but often also for the habitat types with which the Gunnison National Forest stands were compared. Placements of some stands in habitat types described elsewhere are tentative. Some previously described habitat types may have been floristically the same or different from the habitat types sampled in the study area. The low number of stands sampled for each habitat type also was a source of difficulties in deciding whether low-altitude and high-altitude related stands belong to the same or different habitat types. An example is the *Abies lasiocarpa*/*Arnica cordifolia* habitat type, which occurs in both the upper subalpine and upper montane zones. Some of the associated undergrowth species are different at different elevations.

The habitat type classification presented here can only be considered a preliminary classification and has to be refined by further work on a considerably larger number of samples from a greater geographical area.

Stands were considered successional under the following circumstances. (1) They were dominated by plant species not normally associated with climax vegetation;

also, there was evidence of previous disturbance, but the future direction of succession could be predicted. (2) There was strong evidence of severe disturbance in the stand. In forest stands, recovering or successional status may be suggested by invading young tree seedlings of climax species that are not among present overstory dominants; this indicates that the composition of the climax plant association will be different from the composition of the present plant association. An example is a young *Pinus contorta* stand with *Picea engelmannii* and/or *Abies lasiocarpa* seedlings, and evidence of fire. Strongly disturbed stands were placed directly under the climax habitat type when the presumably original dominants were present and there was no evidence of their replacement. Some of these preliminary habitat types later may be found to be successional. For example, the high cover of successional plant species in some sampled stands was attributed to a high degree of grazing disturbance, and was disregarded in classifying and naming these units; despite a high cover of *Bromus tectorum* in a very old stand of *Pseudotsuga menziesii*, the stand was placed in the *P. menziesii/Festuca idahoensis* habitat type on the basis of evidence from remnants of the original undergrowth.

Misinterpretation of the successional status of a stand also may occur, because some plant species that usually dominate successional communities on zonal surfaces also dominate climax communities in azonal habitats where zonal dominants cannot grow. For example, *Populus tremuloides* and *P. menziesii* may dominate climax communities on rocky sites, and also are very successful dominants of recovering and grazing-maintained plant communities in zonal habitats.

One of the most difficult disturbance factors to analyze is grazing. Some plant communities presently are recovering from a severe, one-time disturbance initiated by grazing that may have changed the species composition completely. Other communities occasionally may be disturbed by infrequent livestock grazing that produces a slight but persistent change in species composition. For example, in the subalpine zone, cattle grazing usually decreases the dominance of native graminoids, and increases the cover of various forbs and/or introduced graminoids; sheep grazing may reduce palatable forbs. Other plant communities may be maintained by grazing. These zootic climax plant communities have a species composition very unlike the original natural vegetation.

All these stands probably could be included within a habitat type named for the original climax vegetation. However, how long climax undergrowth vegetation persists under a continuing grazing regime is unknown. Moreover, it eventually may produce a different but stable plant community and a different soil type. The stand then probably should be classified as a new habitat type or at least a different community type.

The stands that were evaluated as successional because of human or fire disturbance were placed under a climax habitat type, into which they presumably would develop in the future. Usually, these were neighboring stands relatively undisturbed, which represented a control for the disturbance. Only control series could be determined when there was no obvious climax habitat type in the vicinity. It was not possible to objectively demonstrate consistent relationships between the stands recovering from disturbance and relatively undisturbed stands.

Both zonal and azonal climax forest communities recover after catastrophic disturbance in various successional stages. Recovering vegetation usually consists of successional plant communities that may be specific for different climax plant communities. Several recovering plant communities may follow each other in a successional sequence before the stage of a climax plant community is reached. For example, a *Populus tremuloides/Festuca thurberi* plant community may be succeeded by a *Pinus contorta/Vaccinium myrtillus* plant community that is in turn succeeded by an *Abies lasiocarpa/Vaccinium myrtillus* habitat type that is climax. Even for the same control or climax plant association, recovering plant communities may be different in each elevational zone, but they also may overlap between zones. In the study area, extensive logging keeps much of the forest vegetation in a successional or disturbed state. The recovery usually is more complex at middle than at higher or lower elevations, and in zonal than in azonal habitat types. In the latter, the recovery may lead directly to the original forest vegetation without the development of successional plant communities.

ECOSYSTEM PATTERNS

There are three major geographical divisions of the study area based on differences in local climate: (1) the northern part of the Gunnison Basin is cooler and receives considerably more precipitation than the rest of the study area; (2) the southern part of the Gunnison Basin has temperatures higher than average for the Basin and is drier; and (3) the Paonia District has considerably higher temperatures and lower precipitation than the Gunnison Basin. Some of the landforms and vegetation within these three areas are strikingly different.

The Paonia District is the only area within the Gunnison National Forest with extensive woodland zone plant communities of *Quercus gambelii* and *Juniperus osteosperma*. *Q. gambelii* is not an important successional species in the study area; it is much more important in this role to the south of the Gunnison National Forest (DeVelice et al. 1986). *Picea pungens* dominates other than streamside plant communities only in the southern part of the Gunnison Basin. Its importance increases toward the south, especially south of the study area; *Pinus edulis* and *Abies concolor*, which also are important in the southwest (DeVelice et al. 1986, Moir and Ludwig 1979), were not found during the present study. In the southern part of the study area, *P. pungens* and *Pseudotsuga menziesii* form a dryland forest near Cathedral (Barrell 1969). *P. menziesii-P. pungens*-dominated forests also occur on well-drained sites southeast of Sargents in the eastern part of the study area. However, these forest associations were not sampled during the present study. The relatively high precipitation in the Gothic area and in the Ruby Moun-

tains probably maintains the luxuriant subalpine forest and undergrowth vegetation in this area. These local climate-related differences are strongest at lower elevations, although they still are noticeable in the upper subalpine zone. Precipitation increases and temperature decreases with elevation, and the differences among local areas are shifted to the area of humid conditions where they do not affect the vegetation as strongly as in the areas of low precipitation where environmental conditions for many species are marginal.

Climatic and edaphic differences may contribute to the predominance of *Pinus contorta* in the Taylor Park region and in the southern part of the study area. These forests, like *Populus tremuloides* forests, may be maintained by fire reoccurring at long time intervals. *Pinus aristata* stands probably are the result of both the distribution opportunity and local climatic differences; large stands are limited to the southern part of the Gunnison National Forest. Poorly developed *Juniperus scopulorum* stands were observed only near Almont and on Alpine Road but were not sampled. According to Barrell (1969), *Abies lasiocarpa* is considerably less frequent in the southern part of the Gunnison Basin, but it was sampled there during the present study.

Soil chemistry may influence vegetation locally; Langenheim (1962) observed a restrictive edaphic situation on North Italian Mountain near Crested Butte and in two other localities. The major influence of soil is through topography. For example, the San Juan Mountains in that part of the Uncompahgre National Forest sampled are considerably steeper than the rest of the study area, except for small sections like the Gothic Natural Research Area in the north. The steep areas have significantly higher erosion rates, particularly if precipitation is higher also, and support more scree vegetation types than areas with gentler topography. In the steep, humid areas, the vegetation also is significantly affected by frequent landslides and snow avalanches that do not occur in arid areas with gentle topography. Soils with high clay content in the Paonia District and in the southern part of the study area may contribute to the predominance of some species there.

A number of habitat types that may occur in the study area were not sampled. The survey was limited to the vicinity of roads; old forest stands that have not been logged may occur in inaccessible areas. Moreover, the plots sampled were frequently small and limited in number. Two habitat types that were not identified in the present study, but may occur at Snodgrass Mountain north of Crested Butte, are *Populus tremuloides/Carex geyeri* and *Abies lasiocarpa/Paxistima myrsinites*.[11] The latter occurs on cool, dry, rocky, steep north slopes. Another habitat type that may occur at cold, dry, higher elevations, such as Alpine Plateau, is *Abies lasiocarpa/Ribes* spp. There is probably at least one *Pseudotsuga menziesii/Picea pungens*-dominated dry land habitat type near Cathedral and southwest of Sargents. Komarkova[3] also identified a *Pinus contorta/Carex foenea* habitat type in an open, dry, south slope below Old Monarch Pass. However, this plant community appears to be successional to an *A. lasiocarpa*-dominated overstory with undetermined undergrowth.

Forest soils, like forest vegetation, also exhibit regional patterns. The northern part of the study area and the neighboring areas to the north appear to have more leached soils than the southern part of the study area or the Paonia District, where the soils are drier and include more clay. These differences probably are more related to the local climate, which is more humid in the north and drier in the south and in the Paonia District. In general, there was little evidence of leaching in the subsurface horizons, and relatively few alfisols were found. These soils are considerably more common in northern Colorado areas, such as the Front Range (Hess and Alexander 1986). The basic geological material probably influences the soil types to some degree. For example, soils in areas with parent materials that produce rounded topography are considerably better developed than in those that produce steep, rocky slopes, such as the Gothic Research Natural Area and the San Juan Mountains.

FURTHER STUDIES IN RELATION TO THE HABITAT TYPES

Several areas of research logically should follow this study. The production of undergrowth vegetation in relation to habitat types needs to be examined. Ellison and Houston (1958) and Mueggler (1985b) have suggested that production of vegetation under *Populus tremuloides* could be used as an indicator of forage production and, therefore, range condition. In the Gunnison National Forest, both cattle and sheep utilize—sometimes quite heavily—vegetation under *Populus*. It would be valuable to know the relationship between habitat types and potential undergrowth productivity.

A correlation may be found between the growth rates of important timber trees and the habitat types in this area similar to the relationship of growth rates of *Pinus ponderosa* and the habitat types in the northern Rocky Mountains described by Daubenmire (1961).

Numerous fungi attack *P. tremuloides* in Colorado (Juzwik et al. 1978). Some *Populus* habitat types may be more susceptible to various species of fungi than others are. In northern Idaho and eastern Washington, *Arceuthobium* infects *P. ponderosa* in the *P. ponderosa/Agropyron spicatum* and *P. ponderosa/Purshia tridentata* habitat types but not in other habitat types dominated by *P. ponderosa* (Daubenmire 1961). Susceptibility of *Picea engelmannii* to insect infestation may be correlated with habitat types in Colorado (Shepherd 1959).

The relationship of forest habitat types and their successional stages to wildlife management also needs further research.

[11] *The Populus tremuloides/Carex geyeri and Abies lasiocarpa/Paxistima myrsinites habitat types were identified and described on the White River National Forest to the north of the Gunnison National Forest by Hess and Wasser[2] and Hoffman and Alexander (1983).*

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Table A-1.—Tree populations for selected habitat types. Numbers of trees listed are based on sample plot data adjusted to 375 m^2.

Habitat type and species	Stands sampled	Seedling height (dm)			Diameter classes (d.b.h.) dm							
		0-6	6-24	24+	0.5-1	1-2	2-3	3-4	4-5	5-6	6-7	7+
Pinus ponderosa/ Festuca arizonica	1											
Pinus ponderosa		0	0	0	1	1	5	1	1	1	1	0
Picea pungens/ Festuca arizonica	1											
Picea pungens		3	6	1	2	6	2	0	0	1	0	0
Pinus aristata		1	0	0	0	0	0	0	0	0	0	0
Picea pungens/ Amelanchier alnifolia	1											
Picea pungens		11	5	13	21	11	6	2	3	0	0	3
Pseudotsuga menziesii		2	3	3	0	1	0	0	0	0	0	0
Pinus ponderosa		0	0	0	0	0	0	2	0	0	0	0
Pseudotsuga menziesii/ Paxistima myrsinites	1											
Pseudotsuga menziesii		4	2	2	0	1	0	1	1	2	2	11
Pseudotsuga menziesii/ Carex geyeri	2											
Pseudotsuga menziesii		8	12	10	6	12	3	3	2	2	0	0
Pinus ponderosa		0	0	0	3	4	3	([1])	([1])	([1])	0	0
Picea pungens		0	2	0	0	0	0	0	0	0	0	0
Populus tremuloides/ Symphoricarpos oreophilus	1											
Populus tremuloides		35	23	79	9	4	14	12	3	1	0	0
Populus tremuloides/ Pteridium aquilinum	1											
Populus tremuloides		29	8	4	13	20	16	9	2	0	0	0
Populus tremuloides/ Amelanchier alnifolia-Prunus virginiana	1											
Populus tremuloides		49	155	55	0	9	31	19	0	0	0	0
Pinus contorta/ Juniperus communis	1											
Pinus contorta		22	7	5	16	21	4	1	2	2	0	0
Picea engelmannii		2	0	0	0	0	0	0	0	0	0	0
Pinus contorta/ Carex geyeri	1											
Pinus contorta		2	0	3	5	10	4	4	2	1	0	0
Picea engelmannii		0	1	1	0	0	0	0	0	0	0	0
Pinus aristata/ Festuca arizonica	3											
Pinus aristata		1	2	2	1	6	8	4	2	0	0	([1])
Picea pungens		2	0	0	0	0	0	0	0	0	0	0
Populus tremuloides		([1])	([1])	0	0	0	0	0	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium	1											
Abies lasiocarpa		40	12	3	1	3	8	0	0	0	0	0
Picea engelmannii		28	16	3	4	6	5	7	1	3	1	0
Abies lasiocarpa/ Polemonium pulcherrimum	1											
Abies lasiocarpa		3	5	1	1	1	1	0	0	0	0	0
Picea engelmannii		8	12	5	10	5	1	2	6	4	3	1
Abies lasiocarpa/ Moss	1											
Abies lasiocarpa		0	0	0	0	0	0	0	0	0	0	0
Picea engelmannii		5	8	1	4	12	16	4	5	2	0	0
Abies lasiocarpa/ Carex geyeri	2											
Abies lasiocarpa		24	12	([1])	3	2	([1])	([1])	0	0	0	0
Picea engelmannii		28	25	11	9	10	4	0	([1])	2	1	2
Pinus contorta		([1])	4	3	2	4	2	2	4	([1])	0	0
Abies lasiocarpa/ Arnica cordifolia	1											
Abies lasiocarpa		76	20	8	13	22	15	2	2	0	0	0
Picea engelmannii		0	1	2	1	4	5	2	3	3	1	2

[1]*Less than one tree per class.*

Table A-2.—Percentage canopy cover of plant species in *Juniperus osteosperma* and *Quercus gambelii* habitat types on the Gunnison National Forest.

	J. osteosperma/ Symphoricarpos oreophilus	***Q. gambelii/ Amelanchier alnifolia***		***Q. gambelii/ Prunus virginiana***
Stand number	**201**	**187**	**207**	**193**
Plot size (m^2)	75	55	55	50
Location:				
Quarter section	NE	SE	NE	SE
Section	5	21	34	16
Township	15S	49N	12S	49N
Range	91W	6W	91W	6W
Landform:				
Slope (%)	5	27	27	11
Aspect	ESE	SE	E	SE
Elevation (m)	2,183	2,929	1,963	2,793
Elevation (ft)	7,160	9,615	6,440	9,165
Tree d.b.h. (cm)	75.0	0.0	0.0	0.0
Shrub d.r.c (cm)	3.0	10.0	12.0	12.0
Tree height (m)	7.0	0.0	0.0	0.0
Shrub height (m)	1.0	2.7	5.0	3.0
Soil pH	7.9	7.4	6.1	6.5
Trees				
Juniperus osteosperma	85.0	--	--	--
Shrubs				
Acer glabrum	--	--	3.0	--
Amelanchier alnifolia	0.4	15.0	6.0	--
Artemisia tridentata	0.2	--	--	--
Mahonia fremontii	3.0	--	--	--
Mahonia repens	--	8.0	15.0	3.0
Paxistima myrsinites	--	--	5.0	--
Prunus virginiana	--	12.0	2.0	15.0
Quercus gambelii	--	65.0	85.0	90.0
Rosa woodsii	3.0	8.0	0.2	--
Swida sericea	--	--	6.0	--
Symphoricarpos oreophilus	65.0	15.0	5.0	7.0
Graminoids				
Bromus carinatus	6.0	--	--	--
Bromus pumpellianus	--	--	3.0	--
Bromus tectorum	18.0	--	--	--
Carex geyeri	20.0	35.0	10.0	40.0
Elymus elymoides	3.0	--	--	--
Elymus trachycaulus	3.0	5.0	0.2	--
Festuca thurberi	--	--	--	12.0
Poa nemoralis ssp. *interior*	8.0	--	--	--
Stipa nelsonii	--	--	--	3.0
Stipa pinetorum	6.0	--	--	--
Forbs				
Achillea lanulosa	3.0	2.0	0.2	--
Allium geyeri	1.0	--	--	--
Castilleja linearifolia	2.0	--	--	--
Chenopodium fremontii	0.4	--	--	--
Cirsium undulatum	0.6	--	--	--
Conioselinum scopulorum	--	--	--	20.2
Erigeron speciosus	2.0	--	--	0.2
Fragaria virginiana	--	--	--	--
Frasera speciosa	2.0	--	--	--
Galium septentrionale	3.0	6.0	--	--
Geranium richardsonii	2.0	--	--	0.2
Heliomeris multiflora	--	4.0	--	--
Lathyrus leucanthus	--	25.0	0.2	2.0
Linum lewisii	--	2.0	--	--
Lomatium dissectum	--	2.0	--	--
Lupinus argenteus	--	6.0	--	--
Osmorhiza depauperata	2.0	--	2.0	--
Senecio serra	3.0	--	--	--
Smilacina stellata	--	1.0	8.0	--
Streptopus fassettii	--	--	1.0	--
Taraxacum officinale	0.4	--	--	--
Thalictrum fendleri	5.0	--	--	--
Vicia americana	0.2	--	--	--
Viola canadensis	3.0	--	--	--
Tree layer	85.0	0.0	0.0	0.0
Shrub layer	4.0	85.0	98.0	93.0
Herbaceous layer	30.0	65.0	30.0	55.0
Rock	2.0	5.0	5.0	1.0
Bare soil	24.0	20.0	3.0	3.0
Moss and lichen	15.0	0.5	12.0	0.0

Table A-3.—Percent canopy cover of plant species in *Pinus ponderosa* and *Picea pungens* habitat types of the Gunnison National Forest.

	P. ponderosa/ Festuca arizonica		*P. ponderosa/ Festuca idahoensis*	*P. pungens/ Festuca arizonica*		*P. pungens/ Amelanchier alnifolia*	
Stand number	**157**	**228**	**174**	**225**	**227**	**203**	**211**
Plot size (m^2)	300	375	200	375	375	20	375
Location:							
Quarter section	NE	NW	NE	SE	NW	SW	SE
Section	15	14	3	25	30	4	28
Township	45N	45N	46N	44N	44N	11S	13S
Range	1E	3E	4W	3W	2W	90W	89W
Landform:							
Slope (%)	31	12	11	12	20	70	36
Aspect	E	SE	S	ESE	E	E	NW
Elevation (m)	3,012	3,030	2,670	3,014	2,973	2,407	2,039
Elevation (ft)	9,880	9,940	8,760	9,890	9,820	7,900	6,690
Tree d.b.h. (cm)	75.0	35.0	35.0	25.0	30.0	40.0	40.0
Shrub d.c.r. (cm)	1.5	1.0	5.0	0.8	1.0	1.0	3.0
Tree ht. (m)	25.0	25.0	9.0	20.0	30.0	18.0	30.0
Shrub ht. (m)	1.2	0.9	0.6	0.8	0.5	0.9	1.0
Soil pH	7.1	--	7.1	--	6.7	--	--
Trees							
Picea pungens	--	--	--	25.0	35.0	85.0	70.0
Picea aristata	--	3.0	--	0.2	10.0	--	--
Pinus ponderosa	35.0	40.0	50.0	--	--	--	4.0
Populus tremuloides	--	--	--	--	--	3.0	--
Pseudotsuga menziesii	5.0	--	--	--	--	--	8.0
Shrubs							
Amelanchier alnifolia	--	--	--	--	--	6.0	8.0
Artemisia tridentata	--	--	65.0	--	--	--	--
Juniperus communis	--	1.0	--	--	2.0	--	--
Lonicera involucrata	--	--	--	--	--	4.0	--
Mahonia repens	--	--	1.0	--	--	--	3.0
Paxistima myrsinites	--	--	--	--	--	2.0	2.0
Prunus virginiana	--	--	--	--	--	3.0	2.0
Quercus gambelii	--	--	--	--	--	0.2	3.0
Ribes cereum	3.0	--	--	4.0	7.0	--	--
Ribes inerme	--	3.0	--	--	--	6.0	5.0
Rosa woodsii	--	--	0.2	2.0	5.0	6.0	8.0
Salix drummondii	--	--	--	--	--	2.0	--
Salix exigua	--	--	--	--	--	--	3.0
Swida sericea	--	--	--	--	--	--	8.0
Symphoricarpos oreophilus	--	--	--	--	--	6.0	6.0
Graminoids							
Agrostis hiemalis	--	--	1.0	--	--	7.0	3.0
Bromus porteri	--	--	--	--	--	8.0	4.0
Calamagrostis canadensis	--	--	--	--	--	2.0	--
Carex geophila	3.0	--	4.0	2.0	--	--	--
Carex geyeri	--	--	--	--	3.0	6.0	--
Carex lanuginosa	--	--	--	--	--	--	6.0
Carex utriculata	--	--	--	--	--	--	2.0
Danthonia parryi	--	--	--	8.0	1.0	--	--
Elymus elymoides	--	2.0	--	--	1.0	--	--
Elymus longifolius	--	0.5	0.2	2.0	1.0	--	--
Elymus trachycaulus	--	0.5	--	--	--	4.0	2.0
Festuca arizonica	30.0	18.0	--	18.0	18.0	--	--
Festuca idahoensis	--	--	6.0	--	--	--	--
Festuca thurberi	--	--	--	--	--	8.0	--
Koeleria macrantha	0.2	3.0	2.0	3.0	2.0	--	--
Muhlenbergia montana	--	22.0	--	2.0	--	--	--
Oryzopsis hymenoides	2.0	0.5	--	1.0	0.5	--	--
Poa nemoralis ssp. *interior*	3.0	--	--	--	--	--	--

Table A-3.—Continued.

Stand number	*P. ponderosa/ Festuca arizonica* 157	*P. ponderosa/ Festuca arizonica* 228	*P. ponderosa/ Festuca idahoensis* 174	*P. pungens/ Festuca arizonica* 225	*P. pungens/ Festuca arizonica* 227	*P. pungens/ Amelanchier alnifolia* 203	*P. pungens/ Amelanchier alnifolia* 211
Forbs							
Achillea lanulosa	--	--	--	--	--	2.0	3.0
Androsace septentrionalis	--	1.0	--	--	0.2	--	--
Antennaria rosea	--	2.0	--	1.0	--	0.2	4.0
Arabis spp.	0.2	0.5	--	0.5	--	--	--
Artemisia frigida	2.0	3.0	0.2	3.0	2.0	--	--
Castilleja spp.	--	1.0	0.2	--	--	--	--
Chaenactis douglasii	0.2	2.0	--	--	--	--	--
Chamerion angustifolium	--	--	--	--	--	--	2.0
Cirsium spp.	--	--	0.2	--	--	--	4.0
Equisetum arvense	--	--	--	--	--	3.0	--
Erigeron glabellus	--	8.0	--	--	--	--	--
Erigeron speciosus	--	--	--	--	--	--	3.0
Erigeron subtrinervis	1.0	1.0	0.2	--	--	--	--
Fragaria virginiana	--	--	--	--	--	0.2	3.0
Galium triflorum	--	--	--	--	--	2.0	--
Geranium cespitosum	--	3.0	--	2.0	3.0	--	--
Geranium richardsonii	--	--	--	--	--	3.0	3.0
Geum rivale	--	--	--	--	--	2.0	--
Heracleum sphondylium	--	--	--	--	--	--	3.0
Heterotheca villosa	--	--	--	3.0	1.0	--	--
Hippochaete laevigata	--	--	--	--	--	--	2.0
Hymenoxys richardsonii	4.0	8.0	--	--	--	--	--
Lathyrus leucanthus	--	--	--	0.5	--	--	1.0
Lupinus argenteus	--	--	5.0	--	--	--	--
Mertensia lanceolata	--	--	--	1.0	3.0	--	--
Osmorhiza depauperata	--	--	--	--	--	3.0	6.0
Penstemon teucrioides	--	--	0.5	--	--	--	--
Potentilla hippiana	--	2.0	1.0	0.5	1.0	--	--
Pulsatilla patens	--	--	1.0	--	--	--	--
Rudbeckia ampla	--	--	--	--	--	--	4.0
Selaginella densa	--	--	--	3.0	--	--	--
Senecio neomexicanus	0.2	--	--	--	0.5	--	--
Senecio serra	--	--	--	--	--	--	3.0
Smilacina amplexicaulis	--	--	--	--	--	--	5.0
Smilacina stellata	--	--	--	--	--	5.0	2.0
Solidago multiradiata	0.2	--	--	--	—	4.0	--
Thalictrum fendleri	--	--	--	--	--	--	3.0
Valeriana acutiloba	--	--	0.2	--	--	--	--
Viola vallicola	--	--	--	--	--	2.0	5.0
Tree layer	45.0	40.0	50.0	25.0	45.0	85.0	75.0
Shrub layer	3.0	4.0	65.0	7.0	7.0	30.0	35.0
Herbaceous layer	40.0	75.0	18.0	30.0	28.0	55.0	45.0
Rock	5.0	10.0	8.0	70.0	70.0	5.0	4.0
Bare soil	60.0	75.0	25.0	60.0	30.0	15.0	1.0
Moss and lichen	2.0	2.0	--	4.0	2.0	8.0	20.0

Table A-4.—Percentage canopy cover of plant species in *Pseudotsuga menziesii* habitat types of the Gunnison National Forest.

	P. menziesii/ Purshia tridentata		*P. menziesii/ Jamesia americana*	*P. menziesii/ Paxistima myrsinites*	*P. menziesii/ Symphoricarpos oreophilus*		*P. menziesii/ Carex geyeri*		*P. menziesii/ Festuca idahoensis*
Stand number	**100**	**92**	**90**	**214**	**141**	**170**	**222**	**221**	**152**
Plot size (m^2)	200	200	200	375	200	150	375	375	150
Location:									
Quarter section	NW	SW	NW	NW	--	NE	SW	SE	SW
Section	20	22	1	23	34	8	32	20	19
Township	49N	49N	48N	14S	14S	42N	50N	50N	45N
Range	3E	5E	5E	87W	84W	4W	89W	88W	2E
Landform:									
Slope (%)	14	21	32	58	21	70	11	21	14
Aspect	SW	S	S	NW	E	W	ENE	SW	E
Elevation (m)	2,829	2,988	2,988	3,024	2,720	2,836	2,426	2,975	3,024
Elevation (ft)	9,280	9,600	9,600	9,900	8,925	9,305	7,960	9,760	9,920
Tree d.b.h. (cm)	35.0	38.0	67.0	80.0	60.0	40.0	30.0	38.0	85.0
Shrub d.c.r. (cm)	8.0	1.5	1.5	2.0	1.5	1.5	1.0	0.5	1.5
Tree ht. (m)	12.0	11.0	18.0	35.0	28.0	20.0	30.0	29.0	18.0
Shrub ht. (m)	0.6	0.6	0.9	0.9	0.4	1.6	0.7	0.6	1.5
Soil pH	6.3	7.2	7.4	--	6.2	7.5	--	--	7.4
Trees									
Picea pungens	--	--	--	--	--	--	1.0	--	--
Pinus contorta	--	25.0	20.0	--	--	--	--	--	--
Pinus flexilis	--	--	6.0	--	1.0	--	--	--	--
Pinus ponderosa	20.0	--	--	--	--	--	45.0	--	--
Populus tremuloides	0.2	12.0	8.0	--	--	--	--	2.0	--
Pseudotsuga menziesii	15.0	25.0	35.0	38.0	60.0	75.0	35.0	70.0	55.0
Shrubs									
Amelanchier alnifolia	--	--	--	3.0	--	--	4.0	--	--
Arctostaphylos adenotricha	--	12.0	4.0	--	--	--	4.0	--	--
Artemisia tridentata	60.0	1.0	0.2	--	--	--	--	--	--
Holodiscus dumosus	2.0	--	--	6.0	--	--	--	--	--
Jamesia americana	--	--	7.0	--	--	--	--	--	--
Juniperus communis	4.0	5.0	1.0	--	--	--	5.0	--	0.2
Mahonia repens	3.0	2.0	8.0	6.0	--	--	20.0	6.0	--
Paxistima myrsinites	1.0	--	--	12.0	--	--	1.0	1.0	--
Prunus virginiana	--	--	--	--	--	--	0.5	--	--
Purshia tridentata	15.0	30.0	--	--	--	--	3.0	--	--
Quercus gambelii	--	--	--	--	--	--	3.0	--	--
Ribes cereum	--	--	--	--	--	--	--	--	3.0
Ribes coloradense	--	--	--	2.0	--	--	--	--	--
Ribes inerme	--	--	0.2	6.0	3.0	3.0	--	5.0	--
Rosa woodsii	--	2.0	2.0	--	2.0	1.0	2.0	33.0	--
Symphoricarpos oreophilus	--	0.2	0.2	3.0	10.0	4.0	25.0	3.0	--
Graminoids									
Agrostis hiemalis	--	--	--	0.5	--	--	--	--	--
Bromus canadensis	--	--	--	--	--	--	--	4.0	--
Bromus pumpellianus	--	--	--	6.0	--	0.2	2.0	--	--
Carex brevipes	--	--	3.0	--	--	--	--	--	--
Carex foenea	--	8.0	--	--	--	--	--	--	--
Carex geyeri	8.0	0.2	--	30.0	1.0	1.0	35.0	60.0	2.0
Elymus elymoides	--	--	0.1	2.0	--	--	0.5	0.5	0.2
Elymus longifolius	0.2	--	--	--	2.0	--	--	--	--
Elymus trachycaulus	--	--	1.0	2.0	--	0.2	--	1.0	--
Festuca arizonica	2.0	--	--	--	--	--	4.0	--	--
Festuca idahoensis	--	--	--	--	4.0	--	--	--	40.0
Festuca thurberi	--	--	--	4.0	--	1.0	--	--	--
Koeleria macrantha	4.0	4.0	1.0	--	3.0	3.0	0.5	4.0	8.0
Muhlenbergia montana	2.0	--	--	--	--	--	--	--	--
Poa fendleriana	--	--	--	--	--	--	2.0	--	--
Poa leptocoma	--	--	--	3.0	--	--	--	--	--
Poa nemoralis ssp. *interior*	--	--	--	1.0	1.0	2.0	--	1.0	--
Poa pratensis	--	--	2.0	--	--	--	--	--	--
Poa spp.	--	--	--	--	--	--	--	4.0	--
Trisetum spicatum	--	--	--	--	2.0	--	--	--	--

Table A-4.—Continued.

	P. menziesii/ Purshia tridentata		*P. menziesii/ Jamesia americana*	*P. menziesii/ Paxistima myrsinites*	*P. menziesii/ Symphoricarpos oreophilus*		*P. menziesii/ Carex geyeri*		*P. menziesii/ Festuca idahoensis*
Stand number	100	92	90	214	141	170	222	221	152
Forbs									
Achillea lanulosa	0.2	0.2	0.2	1.0	--	1.0	1.0	1.0	--
Androsace septentrionalis	--	--	--	--	--	0.2	--	--	0.2
Antennaria pulcherrima	--	--	--	--	--	--	2.0	0.5	--
Antennaria rosea	0.2	1.0	--	--	0.2	--	3.0	1.0	0.2
Apocynum androsaemifolium	--	--	2.0	--	--	--	--	--	--
Arabis drummondii	0.2	--	1.0	--	--	0.2	0.2	--	3.0
Arnica cordifolia	--	--	--	1.0	--	--	--	--	--
Artemisia frigida	--	0.2	--	--	1.0	0.2	--	--	0.2
Atragene columbiana	--	--	--	--	--	5.0	--	--	--
Castilleja rhexifolia	--	--	--	--	--	--	--	2.0	--
Chamerion angustifolium	--	--	1.0	--	--	--	--	--	--
Descurainia richardsonii	--	--	--	--	--	3.0	--	--	1.0
Draba aurea	--	--	--	--	0.2	0.2	--	--	--
Erigeron speciosus	--	--	--	--	--	--	3.0	3.0	--
Erigeron subtrinervis	0.2	0.4	--	--	--	--	--	--	0.2
Fragaria virginiana	0.2	1.0	--	--	0.2	2.0	0.2	1.0	--
Galium septentrionalie	--	--	--	--	--	--	2.0	1.0	--
Geranium richardsonii	--	--	--	--	--	--	1.0	--	--
Helianthella quinquenervis	--	--	--	10.0	--	--	--	--	--
Heracleum sphondylium	--	--	--	2.0	--	--	--	--	--
Lathyrus leucanthus	--	--	--	1.0	--	--	2.0	2.0	--
Machaeranthera canescens	1.0	--	--	--	--	--	--	--	--
Mertensia ciliata	--	--	--	1.0	--	--	--	--	--
Mertensia lanceolata	--	--	--	--	0.2	7.0	--	--	--
Osmorhiza depauperata	--	--	--	1.0	--	--	--	--	--
Penstemon spp.	0.2	0.5	0.5	1.0	--	--	--	--	--
Potentilla hippiana	0.2	0.4	--	--	--	--	--	--	0.2
Potentilla pulcherrima	--	--	--	--	--	--	1.0	--	0.2
Pulsatilla patens	0.2	--	--	--	--	--	2.0	--	--
Selaginella densa	--	--	--	--	2.0	--	--	--	--
Senecio fendleri	--	--	2.0	--	--	--	--	--	0.2
Senecio neomexicanus	0.2	--	--	--	--	--	--	--	--
Senecio werneriaefolius	--	2.0	--	--	--	--	--	--	--
Smilacina stellata	--	0.2	--	0.5	--	--	1.0	--	--
Solidago multiradiata	--	1.0	2.0	--	--	5.0	1.0	--	--
Thalictrum fendleri	--	--	--	--	0.2	5.0	1.0	1.0	--
Urtica gracilis	--	--	--	25.0	--	--	--	--	--
Veratrum tenuipetalum	--	--	--	90.0	--	--	--	--	--
Vicia americana	--	--	--	1.0	0.4	--	--	1.0	--
Tree layer	35.0	60.0	60.0	38.0	60.0	75.0	75.0	70.0	55.0
Shrub layer	65.0	35.0	10.0	18.0	15.0	8.0	35.0	40.0	3.0
Herbaceous layer	20.0	28.0	25.0	60.0	10.0	35.0	75.0	75.0	50.0
Rock	3.0	5.0	18.0	80.0	18.0	18.0	5.0	2.5	20.0
Bare soil	8.0	18.0	12.0	15.0	25.0	12.0	10.0	1.0	8.0
Moss and lichen	10.0	15.0	5.0	4.0	9.0	5.0	5.0	7.0	2.0

Table A-5.—Percentage canopy cover of plant species in *Populus tremuloides* and *Populus angustifolia* habitat types of the Gunnison National Forest.

	P. tremuloides/ Amelanchier alnifolia-Prunus virginiana		*P. tremuloides/ Thalictrum fendleri*	*P. tremuloides/ Symphoricarpos oreophilus*			*P. tremuloides/ Festuca arizonica*	*P. tremuloides/ Pteridium aquilinum*		*P. tremuloides/ Arctostaphylos adenotricha*	*P. tremuloides/ Festuca thurberi*			*P. angustifolia/ Alnus incana-Swida sericea*
Stand number	**198**	**209**	**38**	**188**	**200**	**210**	**150**	**199**	**208**	**101**	**169**	**233**	**173**	**197**
Plot size (m^2)	60	375	100	150	35	375	35	30	375	300	100	100	100	80
Location:														
Quarter section	SE	SW	SE	NW	SW	SE	NE	SW	SW	SE	SW	SE	NW	SE
Section	32	3	10	21	12	1	36	12	3	32	35	33	23	24
Township	15S	11S	50N	49N	15N	11S	45N	51N	11S	51N	44N	51N	43N	15S
Range	90W	89W	3W	6W	5W	91W	2E	5W	89W	5E	3W	2E	3W	91W
Landform:														
Slope (%)	21	21	7	14	7	5	11	11	3	40	7	--	7	0
Aspect	W	SE	ESE	W	NE	E	E	E	S	S	E	SE	E	Flat
Elevation (m)	2,456	2,450	3,049	2,842	2,718	2,554	2,973	2,573	2,682	3,186	3,179	3,164	3,170	2,186
Elevation (ft)	8,060	8,040	10,000	9,390	8,920	8,380	9,755	8,440	8,800	10,450	10,430	10,380	10,400	7,170
Tree d.b.h. (cm)	40.0	28.0	18.0	28.0	25.0	30.0	35.0	25.0	20.0	35.0	15.0	22.0	15.0	65.0
Shrub d.r.c. (cm)	8.0	3.5	1.0	8.0	1.0	2.5	1.5	6.0	2.0	2.0	1.0	0.2	1.5	11.0
Tree ht. (m)	25.0	20.0	15.0	12.0	8.0	18.0	8.0	9.0	29.0	10.0	10.0	9.0	10.0	30.0
Shrub ht. (m)	4.0	3.0	0.3	0.3	0.7	0.7	0.3	3.0	0.8	0.5	0.2	0.3	0.4	6.0
Soil pH	6.2	--	7.2	7.3	6.1	--	6.5	7.3	--	6.3	6.9	--	6.7	6.6
Trees														
Abies lasiocarpa	--	--	--	--	--	0.2	--	--	--	--	--	--	--	--
Picea engelmannii	--	--	--	--	--	--	--	--	--	--	+	--	1.0	--
Populus angustifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	50.0
Populus tremuloides	75.0	80.0	80.0	88.0	85.0	85.0	60.0	65.0	85.0	40.0	80.0	78.0	80.0	--
Pseudotsuga menziesii	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix amygdaloides	--	--	--	--	--	--	--	--	--	--	--	--	--	30.0
Shrubs														
Acer glabrum	--	6.0	--	18.0	--	--	--	--	--	--	--	--	--	20.0
Alnus incana ssp. *tenuifolia*	4.0	--	--	--	--	--	--	--	--	--	--	--	--	10.0
Amelanchier alnifolia	45.0	30.0	--	--	0.4	6.0	--	--	3.0	--	--	--	--	--
Arctostaphylos adenotricha	--	--	--	--	--	--	--	--	--	2.0	4.0	22.0	--	--
Clematis ligusticifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	20.0
Juniperus communis	--	--	--	--	--	--	1.0	--	--	--	1.0	--	1.0	--
Mahonia repens	--	--	--	70.0	--	1.0	--	--	--	--	--	--	--	--
Paxistima myrsinites	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--
Prunus virginiana	45.0	4.0	--	6.0	--	3.0	--	6.0	--	--	--	--	--	3.0
Ribes inerme	1.0	4.0	--	--	--	--	--	4.0	--	3.0	--	--	--	--
Rosa woodsii	15.0	6.0	2.0	6.0	3.0	--	--	--	--	--	--	--	--	30.0
Rubus parviflorus	--	5.0	--	--	--	--	--	--	--	--	--	4.0	--	--
Salix exigua	--	--	--	--	--	--	--	--	--	--	--	--	--	5.0
Salix ligulifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	2.0
Salix lutea	--	--	--	--	--	--	--	--	--	--	--	--	--	5.0
Salix scouleriana	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--
Sambucus racemosa	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--
Shepherdia canadensis	--	--	--	--	--	--	--	--	--	1.0	1.0	--	--	--
Swida sericea	--	--	--	--	--	--	--	--	--	--	--	--	--	55.0
Symphoricarpos oreophilus	25.0	5.0	--	10.0	65.0	26.0	--	12.0	7.0	2.0	--	--	--	--
Graminoids														
Bromus carinatus	--	--	--	--	6.0	--	--	--	--	--	--	3.0	--	--
Bromus porteri	--	--	12.0	--	--	--	--	--	--	1.0	--	--	--	--
Bromus pumpellianus	--	4.0	--	2.0	--	2.0	--	6.0	4.0	--	1.0	--	2.0	--
Bromus tectorum	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Bromus spp.	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Carex geophila	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--
Carex geyeri	--	--	12.0	12.0	20.0	--	6.0	--	8.0	--	2.0	30.0	2.0	--
Carex hoodii	--	15.0	--	--	--	30.0	--	--	--	--	--	--	--	--
Dactylis glomerata	--	--	--	--	--	--	--	--	--	--	--	--	--	6.0
Danthonia intermedia	--	--	--	--	--	--	--	--	--	--	12.0	--	60.0	--
Elymus longifolius	--	--	--	--	--	--	--	--	8.0	0.4	1.0	--	--	--
Elymus trachycaulus	--	8.0	3.0	--	3.0	3.0	--	15.0	2.0	--	—	3.0	—	2.0
Festuca arizonica	--	--	--	--	--	--	28.0	--	--	--	--	--	--	--
Festuca idahoensis	--	--	8.0	--	--	--	--	--	--	--	--	--	10.0	--
Festuca thurberi	--	--	--	--	--	--	18.0	--	--	--	65.0	10.0	15.0	--
Muhlenbergia montana	--	--	--	--	--	--	8.0	--	--	--	--	--	--	--
Poa agassizensis	--	--	--	--	--	18.0	--	--	--	--	--	--	--	--
Poa epilis	--	--	3.0	--	--	--	--	--	--	--	--	--	--	--
Poa fendleriana	--	--	--	--	--	--	--	8.0	--	--	--	--	--	--
Poa nemoralis ssp. *interior*	1.0	--	--	--	--	--	--	--	--	2.0	1.0	--	--	--
Poa palustris	--	--	--	--	--	--	--	--	--	--	--	--	--	4.0
Trisetum spicatum	--	--	--	0.5	--	0.5	--	--	--	0.2	--	--	--	--
Forbs														
Achillea lanulosa	2.0	2.0	4.0	--	3.0	5.0	2.0	3.0	2.0	--	2.0	2.0	2.0	--
Agoseris glauca	--	--	--	--	--	--	--	--	--	--	2.0	3.0	0.2	--
Angelica ampla	--	--	—	1.0	--	--	--	--	3.0	--	--	--	--	--
Aquilegia coerulea	--	--	2.0	6.0	--	1.0	--	--	--	--	--	--	--	--
Arnica cordifolia	--	--	--	--	--	--	--	--	--	--	--	6.0	--	--
Astragalus alpinus	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--
Chamerion angustifolium	--	2.0	35.0	--	--	--	--	--	1.0	0.2	--	1.0	--	--
Cirsium spp.	--	3.0	5.0	--	--	--	--	2.0	2.0	--	--	--	--	--
Conioselinum scopulorum	—	--	--	6.0	--	0.2	--	--	--	--	--	--	--	--
Delphinium nuttallianum	5.0	--	--	--	--	--	--	--	6.0	--	--	--	--	--
Dipsacus sylvestris	2.0	--	--	--	--	--	--	3.0	4.0	--	--	--	--	--

Table A-5.—Continued.

	P. tremuloides/ Amelanchier alnifolia-Prunus virginiana		*P. tremuloides/ Thalictrum fendleri*	*P. tremuloides/ Symphoricarpos oreophilus*			*P. tremuloides/ Festuca arizonica*	*P. tremuloides/ Pteridium aquilinum*		*P. tremuloides/ Arctostaphylos adenotricha*	*P. tremuloides/ Festuca thurberi*			*P. angustifolia/ Alnus incana-Swida sericea*
Stand number	**198**	**209**	**38**	**188**	**200**	**210**	**150**	**199**	**208**	**101**	**169**	**233**	**173**	**197**
Erigeron glabellus	--	--	--	--	--	5.0	--	--	--	--	--	--	--	--
Erigeron speciosus	--	--	3.0	--	2.0	--	--	--	4.0	--	--	3.0	--	--
Erigeron spp.	2.0	--	--	--	--	--	--	2.0	--	--	1.0	--	0.2	--
Fragaria virginiana	1.0	4.0	5.0	--	2.0	5.0	--	--	3.0	0.2	3.0	1.0	2.0	--
Frasera speciosa	1.0	--	--	--	2.0	--	--	--	--	--	--	--	--	--
Galium triflorum	5.0	5.0	--	3.0	--	--	--	--	--	--	--	--	--	--
Galium septentrionale	--	2.0	--	--	2.0	5.0	--	3.0	3.0	--	--	2.0	--	1.0
Geranium richardsonii	3.0	4.0	--	2.0	2.0	6.0	--	2.0	8.0	--	2.0	--	--	--
Helianthella quinquenervis	--	--	4.0	--	--	--	--	--	--	--	--	2.0	--	--
Heracleum sphondylium	5.0	5.0	--	--	--	--	--	--	6.0	--	--	--	--	6.0
Hippochaete hyemalis	--	--	--	--	--	--	--	--	--	--	--	--	--	15.0
Iris missouriensis	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--
Lathyrus leucanthus	--	3.0	35.0	--	--	0.5	--	--	8.0	--	--	37.0	--	--
Lupinus argenteus	4.0	--	15.0	1.0	2.0	--	15.0	--	--	--	--	0.2	--	--
Mertensia lanceolata	--	--	--	--	--	--	--	--	2.0	--	--	--	--	--
Osmorhiza depauperata	8.0	5.0	--	12.0	2.0	4.0	--	--	6.0	--	--	--	--	--
Oxytropis deflexa	--	--	--	--	--	--	3.0	--	--	--	--	--	--	--
Polemonium pulcherrimum	--	--	--	--	--	--	--	5.0	--	--	--	--	--	--
Potentilla hippiana	--	--	--	--	--	--	1.0	--	--	--	1.0	--	2.0	--
Potentilla pulcherrima	--	--	--	--	--	2.0	--	--	--	--	--	--	--	--
Pseudocymopterus montanus	--	--	--	--	--	--	0.2	--	--	0.2	1.0	2.0	0.2	--
Pteridium aquilinum	--	3.0	--	--	--	--	--	40.0	65.0	--	--	--	--	--
Rudbeckia ampla	--	2.0	--	--	--	6.0	--	--	--	--	--	--	--	--
Senecio bigelovii	--	--	--	--	--	6.0	--	--	--	--	--	--	--	--
Senecio serra	3.0	--	5.0	--	3.0	--	--	--	3.0	--	--	2.0	--	--
Senecio spp.	--	--	--	--	--	--	2.0	--	--	0.4	--	--	0.2	--
Smilacina amplexicaulis	--	--	--	2.0	--	--	--	--	--	--	--	--	--	--
Smilacina stellata	3.0	4.0	--	--	--	--	--	--	2.0	--	0.2	--	0.2	6.0
Solidago multiradiata	--	--	--	--	--	--	--	3.0	--	--	2.0	--	--	--
Solidago spp.	6.0	--	--	0.2	--	--	--	--	--	--	--	2.0	2.0	2.0
Streptopus fassettii	--	4.0	--	--	--	--	--	--	0.2	--	--	--	--	--
Taraxacum officinale	--	--	--	--	0.4	2.0	0.2	--	2.0	--	--	0.2	0.2	0.2
Thalictrum fendleri	8 0	5.0	35.0	--	5.0	8.0	--	3.0	6.0	--	--	2.0	2.0	--
Urtica gracilis	--	2.0	--	--	--	--	--	2.0	--	--	--	--	--	--
Valeriana acutiloba	--	--	--	--	0.2	1.0	--	--	--	--	--	--	--	--
Veratrum tenuipetalum	--	--	--	--	--	--	--	--	2.0	--	--	--	--	--
Verbascum thapsus	--	--	--	--	--	--	--	3.0	--	--	--	--	--	--
Vicia americana	--	2.0	--	--	20.0	1.0	--	--	--	--	--	--	--	1.0
Viola canadensis	--	4.0	--	--	3.0	4.0	--	3.0	1.0	--	--	--	--	--
Viola vallicola	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Tree layer	75.0	80.0	80.0	88.0	85.0	85.0	60 0	65.0	85.0	40.0	80.0	78.0	85.0	80.0
Shrub layer	75.0	45.0	2.0	28.0	65.0	30.0	1.0	18.0	10.0	6.0	2.0	4.0	3.0	80.0
Herbaceous layer	65.0	80.0	95.0	80.0	65.0	80.0	80.0	85.0	90.0	6.0	80.0	93.0	75.0	30.0
Rock	1.0	2.0	2.0	1.0	1.0	2.0	8.0	3.0	1.0	90.0	1.0	1.0	2.0	1.0
Bare soil	4.0	6.0	4.0	5.0	10.0	25.0	5.0	5.0	5.0	3.0	8.0	1.0	15.0	3.0
Moss and lichen	4.0	2.0	--	0.5	1.0	--	8.0	3.0	--	4.0	2.0	--	3.0	--

Table A-6.—Percent canopy cover of plant species in *Pinus contorta* habitat types of the Gunnison National Forest.

	P. contorta/ Juniperus communis		*P. contorta/ Vaccinium scoparium*	*P. contorta/ Carex geyeri*
Stand number	**119**	**235**	**98**	**232**
Plot size (m^2)	200	375	200	375
Location:				
Quarter section	SE	SE	NE	SW
Section	18	11	14	24
Township	15S	15S	49N	48N
Range	83W	82W	5E	6E
Landform:				
Slope (%)	0	9	9	3
Aspect	Flat	SE	W	S
Elevation (m)	2,636	3,243	3,250	2,361
Elevation (ft)	8,650	10,640	10,660	7,745
Tree d.b.h. (cm)	45.0	28.0	60.0	30.0
Shrub d.r.c. (cm)	3.0	2.0	1.0	0.5
Tree ht. (m)	15.0	18.0	12.0	15.0
Shrub ht. (m)	0.3	0.3	0.3	0.3
Soil pH	6.0	--	5.8	--
Trees				
Abies lasiocarpa	--	--	--	--
Picea engelmannii	5.0	5.0	5.0	0.5
Pinus contorta	45.0	70.0	50.0	75.0
Pseudotsuga menziesii	10.0	--	--	--
Shrubs				
Arctostaphylos adenotricha	4.0	5.0	--	--
Juniperus communis	7.0	10.0	3.0	--
Mahonia repens	0.2	--	--	--
Paxistima myrsinites	0.2	--	--	--
Pentaphylloides floribunda	--	2.0	--	--
Ribes montigenum	--	--	--	1.0
Rosa woodsii	0.2	1.0	--	1.0
Shepherdia canadensis	1.0	--	--	--
Symphoricarpos oreophilus	--	--	--	1.0
Vaccinium scoparium	--	--	18.0	--
Graminoids				
Agrostis hiemalis	--	--	--	--
Bromus porteri	--	--	--	4.0
Bromus spp.	--	0.5	--	--
Calamagrostis canadensis	--	--	--	4.0
Calamagrostis purpurascens	--	4.0	--	--
Carex brevipes	--	--	2.0	--
Carex geyeri	0.2	18.0	--	40.0
Elymus elymoides	--	1.0	--	1.0
Elymus trachycaulus	--	--	--	1.0
Festuca idahoensis	--	2.0	--	--
Festuca saximontana	--	1.0	--	6.0
Festuca thurberi	--	--	--	2.0
Koeleria macrantha	0.4	--	--	2.0
Poa fendleriana	0.2	--	--	--
Poa nemoralis ssp. *interior*	--	2.0	--	1.0
Poa nervosa	--	--	--	--
Poa pratensis	--	--	2.0	--
Stipa nelsonii	--	--	--	2.0
Trisetum spicatum	--	0.5	--	2.0

Table A-6.—Continued.

	P. contorta/ Juniperus communis		*P. contorta/ Vaccinium scoparium*	*P. contorta/ Carex geyeri*
Stand number	**119**	**235**	**98**	**232**
Forbs				
Achillea lanulosa	--	--	--	5.0
Androsace septentrionalis	--	0.2	0.2	--
Antennaria spp.	0.2	3.0	1.0	--
Arabis spp.	0.2	0.5	--	--
Arnica cordifolia	--	--	--	25.0
Astragalus alpinus	--	--	--	3.0
Chamerion angustifolium	--	0.5	--	0.5
Erigeron subtrinervis	--	--	--	3.0
Erigeron spp.	0.2	--	--	--
Eriogonum umbellatum	0.2	--	0.2	--
Fragaria virginiana	--	3.0	--	20.0
Oreochrysum parryi	--	--	--	1.0
Oreoxis alpina	--	1.0	--	--
Potentilla spp.	--	1.0	--	1.0
Pulsatilla patens	0.2	--	--	--
Sedum lanceolatum	--	1.0	1.0	--
Selaginella densa	1.0	3.0	--	--
Senecio neomexicanus	--	2.0	1.0	--
Smilacina stellata	--	1.0	--	--
Solidago multiradiata	--	--	1.0	--
Solidago spathulata	--	0.5	--	--
Thlaspi montanus	--	--	0.2	--
Thermopsis montana	--	--	--	4.0
Tree layer	60.0	75.0	55.0	75.0
Shrub layer	8.0	12.0	3.0	3.0
Herbaceous layer	5.0	30.0	25.0	85.0
Rock	18.0	10.0	55.0	3.0
Bare soil	3.0	25.0	20.0	1.0
Moss and lichen	5.0	11.0	20.0	3.0

Table A-7.—Percent canopy cover of plant species in *Pinus aristata* and *Pinus flexilis* habitat types of the Gunnison National Forest.

	P. aristata/ Festuca thurberi	***P. aristata/ Festuca arizonica***					***P. aristata/ Juniperus communis***	***P. flexilis/ Ciliaria austromontana***
Stand number	**110**	**145**	**160**	**224**	**226**	**229**	**143**	**142**
Plot size (m^2)	55	150	75	375	375	375	200	35
Location:								
Quarter section	NE	NE	NW	SE	NE	NW	NE	SW
Section	11	14	21	25	25	14	14	34
Township	51N	45N	44N	44N	44N	45N	45N	14S
Range	4E	3E	2W	3W	3W	3E	3E	84W
Landform:								
Slope (%)	21	14	14	21	51	9	14	53
Aspect	W	SE	E	S	ESE	SE	SE	SSW
Elevation (m)	3,616	3,023	2,878	3,042	3,024	3,011	3,060	2,744
Elevation (ft)	11,865	9,920	9,440	9,980	9,920	9,880	10,040	9,000
Tree d.b.h. (cm)	45.0	35.0	35.0	35.0	30.0	28.0	50.0	50.0
Shrub d.r.c. (cm)	0.8	1.0	2.0	1.0	0.8	1.0	2.0	1.0
Tree ht. (m)	8.0	10.0	12.0	6.0	20.0	15.0	12.0	12.0
Shrub ht. (m)	0.2	0.3	0.8	0.6	0.6	1.0	0.3	0.4
Soil pH	7.7	--	6.0	--	--	--	6.4	6.9
Trees								
Picea engelmannii	15.0	--	--	--	--	--	--	--
Pinus aristata	40.0	58.0	60.0	65.0	40.0	55.0	40.0	--
Pinus flexilis	--	8.0	--	--	--	--	8.0	42.0
Populus tremuloides	--	--	--	1.0	--	--	4.0	--
Pseudotsuga menziesii	--	--	--	--	--	--	25.0	3.0
Shrubs								
Juniperus communis	4.0	--	--	--	--	--	16.0	3.0
Pentaphylloides floribunda	--	--	--	1.0	--	--	--	--
Ribes cereum	--	4.0	2.0	4.0	7.0	5.0	--	--
Ribes inerme	--	--	--	--	--	--	--	3.0
Ribes montigenum	1.0	--	--	--	--	--	--	--
Rosa woodsii	--	--	--	--	--	0.5	2.0	3.0
Symphoricarpos oreophilus	--	--	--	--	--	--	--	5.0
Graminoids								
Agrostis hiemalis	0.2	--	--	--	--	--	--	3.0
Calamagrostis purpurascens	0.5	--	--	--	--	--	--	--
Carex foenea	1.0	--	--	--	--	--	--	--
Carex geophila	--	--	--	0.5	--	0.5	--	4.0
Carex geyeri	--	3.0	3.0	--	2.0	4.0	2.0	--
Danthonia parryi	--	2.0	5.0	3.0	1.0	8.0	0.2	--
Elymus elymoides	--	0.2	--	4.0	1.0	--	--	--
Elymus trachycaulus	2.0	--	--	--	--	--	0.4	--
Festuca arizonica	--	18.0	--	20.0	15.0	20.0	--	--
Festuca idahoensis	--	--	9.0	--	--	1.0	--	--
Festuca thurberi	15.0	--	--	--	--	--	1.0	4.0
Koeleria macrantha	2.0	--	2.0	5.0	1.0	3.0	2.0	--
Muhlenbergia montana	--	5.0	23.0	3.0	2.0	25.0	4.0	--
Oryzopsis hymenoides	--	--	--	--	3.0	--	--	--
Poa fendleriana	0.2	--	--	--	--	--	3.0	--
Poa glauca	3.0	--	--	--	--	--	--	--
Poa nemoralis ssp. *interior*	--	--	--	--	--	--	--	3.0
Poa reflexa	--	--	--	--	--	--	--	2.0

Table A-7.—Continued.

	P. aristata/ Festuca thurberi	*P. aristata/ Festuca arizonica*					*P. aristata/ Juniperus communis*	*P. flexilis/ Ciliaria austromontana*
Stand number	**110**	**145**	**160**	**224**	**226**	**229**	**143**	**142**
Forbs								
Achillea lanulosa	2.0	--	--	--	--	2.0	--	1.0
Androsace septentrionalis	--	0.2	0.2	0.5	0.2	1.0	2.0	--
Antennaria parvifolia	2.0	3.0	--	--	--	1.0	--	--
Arabis spp.	--	--	--	1.0	--	0.2	0.2	0.2
Artemisia dracunculus	--	0.2	--	--	--	--	2.0	--
Artemisia frigida	--	3.0	2.0	4.0	5.0	--	2.0	--
Astragalus agrestis	2.0	--	--	--	--	--	--	--
Astragalus hallii	--	0.2	--	--	--	3.0	--	--
Chaenactis douglasii	0.2	1.0	--	--	--	1.0	0.2	--
Chamerion angustifolium	1.0	--	--	--	--	--	--	--
Ciliaria austromontana	--	--	--	--	--	--	--	10.0
Draba aurea	--	--	--	0.2	--	0.5	--	0.2
Descurainia richardsonii	--	1.0	--	1.0	--	1.0	0.2	0.2
Eremogone fendleri	--	--	--	--	--	1.0	--	--
Erigeron peregrinus	2.0	0.2	--	--	--	--	--	--
Erigeron pinnatisectus	1.0	--	--	--	--	--	--	--
Erigeron subtrinervis	0.2	2.0	--	--	--	1.0	2.0	--
Fragaria virginiana	0.2	--	--	--	--	--	0.2	4.0
Frasera speciosa	2.0	--	--	--	--	--	--	--
Geranium caespitosum	--	1.0	3.0	3.0	3.0	--	--	--
Gilia calcarea	--	--	--	--	--	--	--	1.0
Heterotheca villosa	2.0	--	0.4	0.5	1.0	--	--	0.2
Hymenoxys richardsonii	--	4.0	--	1.0	--	0.5	0.2	--
Lathyrus leucanthus	--	--	--	0.5	--	--	--	--
Machaeranthera canescens	--	--	--	--	--	18.0	--	--
Mertensia lanceolata	0.2	--	0.2	0.3	3.0	--	--	--
Oreoxis alpina	2.0	--	--	--	--	--	--	--
Penstemon spp.	--	--	--	1.0	--	0.5	--	--
Potentilla hippiana	0.2	4.0	0.2	2.0	0.5	1.0	--	0.2
Potentilla pulcherrima	2.0	1.0	--	--	--	0.5	--	--
Pseudocymopterus montanus	2.0	--	--	--	--	--	--	--
Pulsatilla patens	2.0	--	--	--	--	--	--	--
Sedum lanceolatum	1.0	--	--	--	--	--	--	--
Senecio neomexicana	--	--	0.2	2.0	1.0	--	--	--
Senecio werneriaefolia	1.0	--	--	--	--	0.5	--	--
Solidago multiradiata	--	0.2	0.2	--	--	--	--	--
Taraxacum officinale	--	0.2	--	--	--	0.2	--	--
Thlaspi montanus	0.2	--	--	--	--	--	0.2	0.2
Trifolium dasyphyllum	2.0	--	--	--	--	--	--	--
Vicia americana	--	1.0	--	--	--	0.2	--	--
Tree layer	65.0	65.0	60.0	65.0	40.0	55.0	70.0	45.0
Shrub layer	5.0	4.0	2.0	5.0	7.0	5.0	18.0	15.0
Herbaceous layer	35.0	50.0	45.0	40.0	30.0	85.0	15.0	30.0
Rock	2.0	10.0	20.0	90.0	90.0	10.0	12.0	20.0
Bare soil	6.0	65.0	10.0	60.0	60.0	60.0	8.0	10.0
Moss and lichen	6.0	4.0	3.0	2.0	2.0	3.0	4.0	10.0

Table A-8.—Percentage canopy cover of plant species in *Abies lasiocarpa* habitat types on the Gunnison National Fores

	A. lasiocarpa/ Juniperus communis		*A. lasiocarpa/ Vaccinium myrtillus*			*A. lasiocarpa/ Vaccinium scoparium*	*A. lasiocarpa/ Carex geyeri*				*A. lasiocarpa/ Senecio triangularis*	*A. lasiocarpa/ Calamagrostis canadensis*	*A. lasiocarpa/ Polemonium pulcherrimum*		*A. lasiocarpa/ Arnica cordifolia*		*A. lasiocarpa/ Moss*		
Stand number	**154**	**155**	**2**	**93**	**231**	**216**	**206**	**220**	**178**	**234**	**218**	**139**	**215**	**180**	**22**	**212**	**175**	**149**	**223**
Plot size (m^2)	200	200	200	65	100	375	20	375	200	375	25	50	375	200	100	375	200	150	375
Location:																			
Quarter section	--	NW	SE	NW	NW	NE	SW	NW	SE	NW	NW	--	NE	NE	SW	SW	NE	SE	NE
Section	1	12	34	18	30	13	14	8	5	25	20	34	13	29	34	34	23	36	34
Township	44N	44N	47N	49N	48N	12S	11S	49N	45N	51N	12S	14S	12S	46N	51N	13S	46N	45N	44N
Range	1E	1E	5E	6E	6E	87W	92W	3W	4W	3E	86W	84W	87W	4W	3W	88W	5W	3E	6W
Landform:																			
Slope (%)	7	9	3	31	5	12	7	5	3	2	2	5	9	3	7	9	3	7	5
Aspect	NE	E	SE	SSW	NE	NW	SE	ESE	E	ESE	S	S	NW	NW	NW	NE	N	E	NE
Elevation (m)	3,152	3,195	3,470	3,517	2,850	3,231	2,963	3,282	3,134	3,060	3,075	2,720	3,228	3,369	3,314	2,845	3,003	2,970	3,219
Elevation (ft)	10,340	10,480	11,385	11,540	9,350	10,600	8,835	10,770	10,280	10,040	10,090	8,925	10,590	11,050	10,870	9,334	9,850	9,745	10,560
Tree d.b.h. (cm)	18.0	18.0	--	40.0	12.0	38.0	45.0	38.0	45.0	32.0	30.0	50.0	45.0	85.0	55.0	35.0	55.0	35.0	38.0
Shrub d.r.c. (cm)	1.5	2.0	0.8	0.8	1.0	1.0	0.5	1.0	1.0	0.5	0.5	3.0	1.0	1.0	1.0	1.0	0.5	1.0	0.5
Tree ht. (m)	10.0	8.0	18.0	8.0	10.0	29.0	18.0	28.0	35.0	20.0	29.0	25.0	29.0	30.0	8.0	29.0	50.0	22.0	30.0
Shrub ht. (m)	0.5	0.3	0.1	0.6	0.5	0.6	0.5	0.6	0.3	0.4	0.3	0.4	0.5	0.4	0.5	0.6	0.2	0.4	0.2
Soil pH	6.4	6.7	6.4	5.9	--	--	6.0	--	7.0	--	--	6.6	--	6.0	6.3	--	5.3	6.5	--
Trees																			
Abies lasiocarpa	--	--	6.0	--	--	15.0	20.0	35.0	38.0	4.0	25.0	--	20.0	15.0	5.0	45.0	15.0	--	--
Picea engelmannii	35.0	10.0	45.0	10.0	--	60.0	70.0	55.0	15.0	15.0	50.0	78.0	55.0	85.0	78.0	35.0	85.0	85.0	75.0
Pinus contorta	--	--	6.0	60.0	83.0	--	--	--	--	60.0	--	--	--	--	--	--	--	--	--
Populus tremuloides	40.0	60.0	--	--	3.0	--	--	--	50.0	2.0	--	--	--	--	--	--	4.0	3.0	--
Pseudotsuga menziesii	--	--	--	--	--	--	--	--	5.0	--	--	--	--	--	--	--	--	--	--
Shrubs																			
Arctostaphylos adenotricha	5.0	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Juniperus communis	13.0	5.0	2.0	0.2	2.0	--	--	3.0	2.0	6.0	--	--	--	--	--	--	--	2.0	--
Lonicera involucrata	--	--	--	--	--	--	2.0	--	--	--	4.0	6.0	--	--	--	4.0	--	--	--
Mahonia repens	--	--	--	--	--	--	--	--	5.0	6.0	--	--	--	--	--	--	--	--	--
Paxistima myrsinites	--	--	--	--	--	--	--	--	1.0	18.0	--	--	--	--	--	2.0	1.0	--	--
Pentaphylloides floribunda	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.0	--
Ribes coloradense	--	--	--	--	--	3.0	--	--	--	--	--	--	4.0	--	--	--	--	--	--
Ribes inerme	--	--	--	--	--	1.0	3.0	--	--	--	--	--	--	8.0	--	3.0	--	--	--
Ribes montigenum	--	--	--	5.0	--	--	--	--	--	--	--	--	--	--	8.0	--	--	--	2.0
Rosa woodsii	--	--	--	--	1.0	--	--	--	--	1.0	--	3.0	--	--	--	--	1.0	--	--
Salix glauca	--	--	--	--	--	--	--	--	--	--	--	4.0	--	--	--	--	--	--	--
Shepherdia canadensis	12.0	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Swida sericea	--	--	--	--	--	--	--	--	--	--	--	22.0	--	--	--	--	--	--	--
Symphoricarpos oreophilus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.0	--	1.0	--
Vaccinium cespitosum	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--	--	--	--	--	--
Vaccinium myrtillus	--	--	28.0	30.0	70.0	15.0	6.0	--	--	--	2.0	--	6.0	--	--	2.0	+	--	2.0
Vaccinium scoparium	--	--	--	--	--	50.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Graminoids																			
Agrostis hiemalis	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2	--	--	--	--	--
Bromus porteri	--	--	--	--	--	--	--	--	--	--	--	--	--	1.0	--	--	0.2	--	--
Bromus pumpellianus	--	--	--	0.2	--	--	--	--	--	0.5	2.0	--	--	--	3.0	1.0	--	--	--
Bromus spp.	0.2	--	--	--	--	--	--	--	2.0	--	--	--	--	--	--	--	--	--	--
Calamagrostis canadensis	--	--	--	--	--	--	--	--	--	--	--	55.0	--	--	--	--	--	--	--
Carex foenea	--	--	0.2	12.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carex geophila	--	10.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carex geyeri	2.0	--	--	0.2	--	1.0	35.0	15.0	3.0	65.0	--	3.0	--	1.0	--	6.0	1.0	1.0	2.0
Carex utriculata	--	--	--	--	--	--	--	--	--	--	1.0	3.0	--	--	--	--	--	--	--
Carex spp.	--	--	--	--	--	--	3.0	--	--	--	4.0	--	--	--	--	--	--	--	--
Danthonia intermedia	--	--	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Deschampsia cespitosa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elymus elymoides	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Festuca idahoensis	--	30.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Festuca thurberi	--	--	0.2	8.0	--	--	--	--	0.2	--	--	--	--	--	--	--	--	3.0	--
Koeleria macrantha	2.0	6.0	--	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.0
Luzula parviflora	--	--	--	--	--	2.0	--	--	--	--	--	--	5.0	--	--	--	--	--	2.0

Antennaria spp.	0.2	2.0	--	0.2	--	--	--	0.5	--	--	--	--	--	--	--	--	0.2	--	--
Aquilegia coerulea	--	--	--	--	--	--	--	--	--	0.5	--	--	1.0	--	3.0	2.0	--	0.2	--
Arabis spp.	0.2	0.2	--	0.2	--	--	--	0.2	--	--	--	--	--	--	--	--	--	--	--
Arnica cordifolia	--	--	3.0	8.0	--	6.0	--	--	--	8.0	--	--	12.0	--	6.0	10.0	--	--	--
Arnica latifolia	--	--	--	--	25.0	--	--	--	--	4.0	--	--	6.0	--	--	--	--	--	--
Aster spp.	--	--	--	--	--	0.5	--	--	--	--	--	0.2	3.0	--	--	--	--	--	--
Astragalus alpinus	--	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--
Bistorta bistortoides	--	--	--	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--	--	--
Caltha leptosepala	--	--	--	--	--	2.0	--	--	--	--	--	--	18.0	4.0	--	--	--	--	--
Campanula parryi	--	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--
Cardamine cordifolia	--	--	--	--	--	--	--	--	--	--	3.0	--	4.0	--	--	--	--	--	--
Castilleja rhexifolia	--	--	--	--	--	2.0	--	--	--	--	--	--	1.0	--	--	--	--	--	--
Chamerion angustifolium	0.2	0.2	0.2	--	--	0.2	--	--	0.2	0.5	--	0.2	--	--	--	--	--	--	--
Cirsium spp.	--	--	--	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--	--	--
Delphinium nuttallianum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2	--
Draba aurea	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2	--
Draba crassifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5
Equisetum arvense	--	--	--	--	--	--	--	--	--	--	35.0	45.0	--	--	--	--	--	--	--
Erigeron formosissimus	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--	--	20.0	--	--	--
Erigeron spp.	--	0.2	--	--	0.2	--	--	0.2	--	--	--	--	2.0	--	--	--	--	--	--
Fragaria vesca	--	--	--	--	--	1.0	3.0	--	--	--	--	--	--	--	--	--	--	--	--
Fragaria virginiana	2.0	--	2.0	2.0	--	--	--	2.0	3.0	3.0	--	--	--	0.2	3.0	3.0	1.0	--	0.5
Galium septentrionale	--	--	--	--	--	--	0.2	--	--	--	--	--	--	--	--	2.0	--	--	--
Galium triflorum	--	--	--	--	--	--	--	0.2	--	--	--	0.2	--	--	--	--	--	0.2	--
Geranium cespitosum	--	--	--	--	--	--	--	--	--	--	--	1.0	--	--	--	--	--	--	2.0
Geranium richardsonii	--	--	--	--	--	--	--	--	3.0	--	--	--	3.0	--	--	1.0	--	--	--
Heracleum sphondylium	--	--	--	--	--	--	--	--	--	--	3.0	3.0	--	--	--	--	--	--	--
Lathyrus leucanthus	--	--	--	--	--	--	0.2	10.0	15.0	2.0	--	--	--	--	--	0.5	--	--	--
Ligularia bigelovii	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.0
Lupinus argenteus	--	--	--	--	--	--	--	--	--	--	--	--	--	6.0	3.0	--	--	0.2	--
Mertensia ciliata	--	--	--	--	--	0.2	--	--	--	--	--	--	5.0	--	--	--	--	--	2.0
Mitella pentandra	--	--	--	--	--	0.5	--	--	--	--	1.0	--	3.0	--	--	--	--	--	--
Oreochrysum parryi	1.0	--	--	--	1.0	--	--	--	3.0	--	--	--	--	--	--	--	--	--	--
Osmorhiza depauperata	--	--	--	--	--	0.2	2.0	--	--	--	0.5	0.2	4.0	--	--	10.0	--	--	--
Pedicularis grayi	--	--	--	--	--	2.0	--	--	--	--	--	--	1.0	--	--	--	--	--	--
Pedicularis racemosa	--	--	--	--	--	2.0	1.0	--	--	--	3.0	--	3.0	--	3.0	2.0	--	--	--
Penstemon whippleanus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Polemonium pulcherrimum	--	--	2.0	--	--	2.0	--	--	--	--	--	--	8.0	8.0	0.2	1.0	--	--	2.0
Polygonum douglasii	--	--	--	--	--	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--
Potentilla diversifolia	--	--	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potentilla gracilis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.0	--	--	--	--
Potentilla hippiana	0.2	2.0	--	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potentilla pulcherrima	--	--	--	--	--	--	--	2.0	--	--	--	--	--	2.0	--	--	--	--	--
Pseudocymopterus montanus	--	--	+	--	--	0.5	--	--	--	--	15.0	--	2.0	0.2	3.0	--	0.2	0.2	--
Pyrola spp.	--	--	--	--	6.0	--	--	0.2	--	--	--	0.2	--	--	--	--	--	--	--
Ranunculus uncinatus	--	--	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--	--	--
Rorippa palustris	--	--	--	--	--	--	2.0	--	--	--	--	--	--	--	--	--	--	--	--
Sedum lanceolatum	--	--	--	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Senecio integerrimus	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--
Senecio serra	2.0	--	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--	--	--
Senecio triangularis	--	--	--	--	--	3.0	--	--	--	--	4.0	--	3.0	--	--	--	--	--	--
Senecio spp.	0.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5	--	--	--
Smilacina stellata	--	--	--	--	--	--	--	--	--	--	--	4.0	--	--	--	--	--	--	--
Solidago multiradiata	2.0	0.2	--	5.0	--	--	2.0	--	--	1.0	--	--	--	--	--	--	--	--	--
Solidago spathulata	--	--	3.0	--	--	--	--	1.0	--	--	--	--	--	2.0	--	--	0.2	--	0.5
Solidago spp.	--	--	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--
Stellaria longipes	--	--	0.1	--	--	--	--	--	--	--	--	--	--	--	0.2	0.5	+	--	--
Stellaria umbellata	--	--	--	--	--	--	--	--	--	--	2.0	--	1.0	--	--	--	--	--	1.0
Streptopus fassettii	--	--	--	--	--	--	--	--	--	--	25.0	--	--	--	--	--	--	--	--
Thalictrum fendleri	--	--	--	--	--	--	5.0	--	5.0	1.0	--	--	--	--	--	2.0	0.2	0.2	--
Thlaspi montanus	--	--	+	0.2	--	0.2	--	0.2	--	--	--	--	--	0.2	--	--	--	--	2.0
Thermopsis montana	--	--	--	--	25.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Veronica americana	--	--	--	--	--	--	5.0	--	--	--	--	--	--	--	--	--	--	--	--
Tree layer	75.0	70.0	55.0	68.0	85.0	70.0	88.0	80.0	85.0	75.0	70.0	78.0	70.0	95.0	80.0	75.0	85.0	85.0	75.0
Shrub layer	25.0	5.0	2.0	5.0	4.0	3.0	5.0	3.0	3.0	7.0	4.0	35.0	4.0	8.0	8.0	8.0	2.0	4.0	2.0
Herbaceous layer	15.0	55.0	35.0	60.0	85.0	78.0	45.0	30.0	30.0	90.0	80.0	80.0	85.0	25.0	28.0	40.0	2.0	4.0	20.0
Rock	8.0	3.0	6.0	18.0	30.0	1.0	3.0	2.0	2.0	10.0	1.0	2.0	5.0	1.0	11.0	1.0	1.0	2.0	1.0
Bare soil	3.0	15.0	2.0	12.0	1.0	10.0	3.0	1.0	5.0	2.0	1.0	25.0	1.0	10.0	4.0	1.0	3.0	8.0	25.0
Moss and lichen	30.0	4.0	8.0	6.0	4.0	28.0	25.0	20.0	25.0	7.0	35.0	16.0	70.0	20.0	10.0	30.0	50.0	15.0	25.0

Komarkova, Vera; Alexander, Robert R.; Johnston, Barry. C. 1988. Forest vegetation of the Gunnison and parts of the Uncompahgre National Forests: a preliminary habitat type classification. Gen. Tech. Rep. RM-163. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 65 p.

A vegetation classification based on a combination of concepts and methods developed by Braun-Blanquet and Daubenmire was used to identify 37 *tentative* forest habitat types on the Gunnison National Forest. Woodland habitat types comprised two series with a total of 3 habitat types, and forest habitat types included nine series with a total of 34 habitat types. A key to identify the habitat types is provided and the management implications associated with each are discussed.

Keywords: Vegetation classification, habitat type, *Abies lasiocarpa, Picea engelmannii, Pinus aristata, Pinus contorta, Pinus flexilis, Populus tremuloides, Picea pungens, Pseudotsuga menziesii, Pinus ponderosa, Populus angustifolia, Quercus gambelii, Juniperus osteosperma*

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-164

Tools to Manage the Past:

Research Priorities for Cultural Resources Management in the Southwest

Symposium Proceedings

May 2-6, 1988
Grand Canyon, Arizona

Tainter, Joseph A.; Hamre, R. H., eds. 1988. Tools to manage the past: research priorities for cultural resources management in the Southwest; 1988 May 2-6; Grand Canyon, AZ. Gen. Tech. Rep. RM-164. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 214 p.

These proceedings contain 13 solicited papers, plus 9 papers generated during the Grand Canyon workshop, designed to establish what knowledge and technology is needed to make possible more effective management of cultural resources in the Southwest. Workshops were organized around the topics: management impacts, Native American heritage, protection and preservation, site discovery and definition, public interpretation and education, key prehistoric research, key historic research, and integrated research designs.

NOTE

To produce these proceedings quickly, we asked authors of solicited papers to submit their papers in camera-ready form. Papers developed by the working groups during the week at Grand Canyon did not receive conventional peer or full editorial review. Thus readers may notice a few typographical errors, or slight differences in format. Also, the views expressed in each paper are those of the authors, and are not necessarily those of the sponsoring organizations.

Cover Photo:
Gila Cliff Dwellings, Gila Wilderness, July, 1939.
Photo by W. H. Shaffer

USDA Forest Service
General Technical Report RM-164

1988

Tools to Manage the Past:

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May 2-6, 1988
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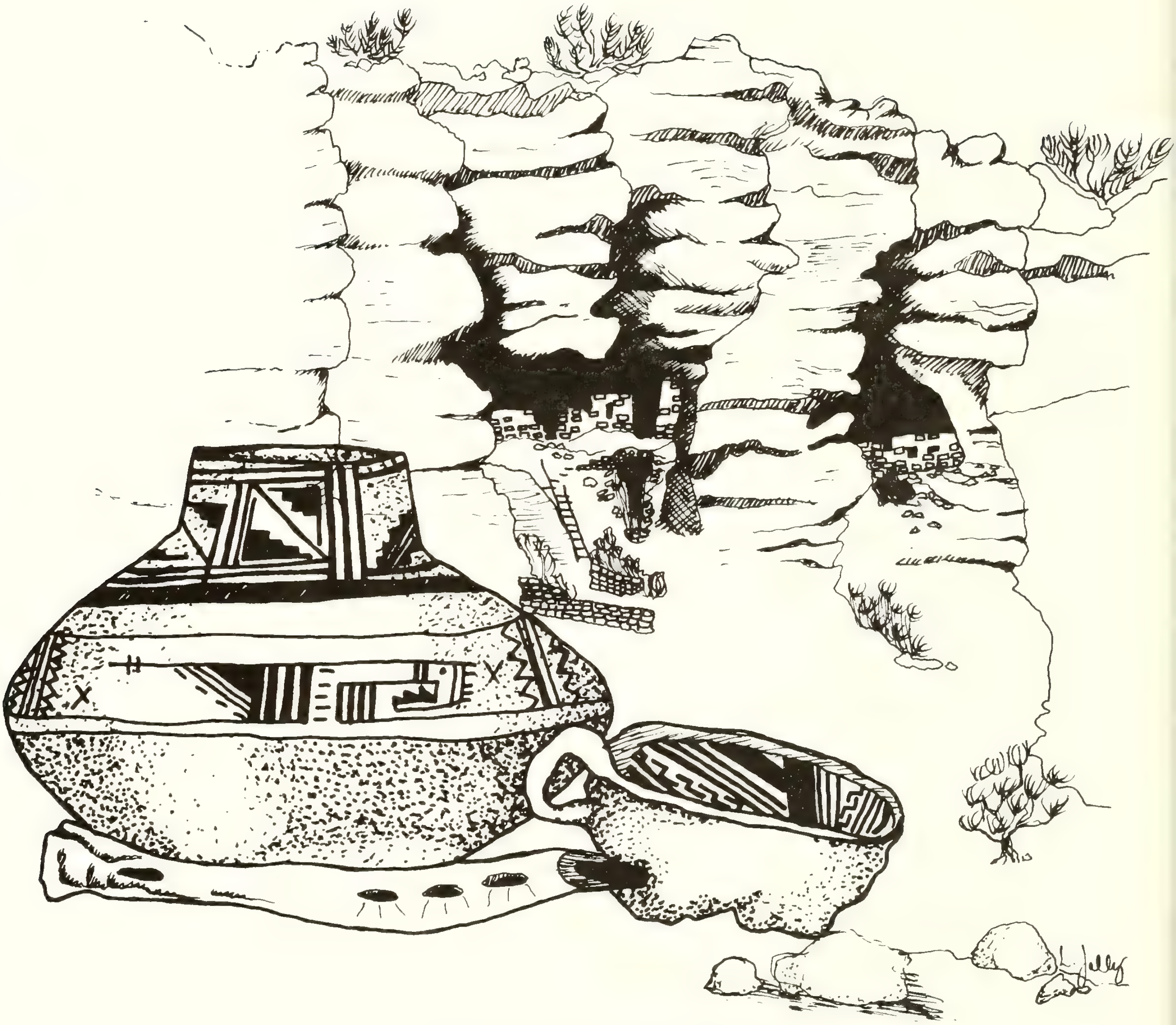
Editors:

Joseph A. Tainter, Cibola National Forest
R. H. Hamre, Rocky Mountain Forest and Range Experiment Station

Sponsors:

USDA Forest Service,

Southwestern Region
and
Rocky Mountain Forest and Range Experiment Station



Gila Cliff Dwelling, Gila Wilderness
(drawn by Linda Jolly)

Contents

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*Presented on the opening day of the symposium.

Introduction[1]

Judith G. Propper[2] and Joseph A. Tainter[3]

The idea to convene the "Tools to Manage the Past" symposium grew out of a 1986 General Management Review (GMR) of the Southwestern Region and the Rocky Mountain Forest and Range Experiment Station. In the opening remarks of their report the GMR team members[4] made the following observations about cultural resources:

> The Southwestern Region includes a vast array of cultural resources. They include prehistoric cliff dwellings, Pueblo ruins, Spanish Colonial and Mexican settlements, and various types of early mining, ranching, and logging sites. Many of these resources can be traced forward into modern times to contemporary Native American populations still occupying these lands. These resources are unique to North America and represent a scientific, historical, and religious treasure of incalculable value.[5]

Cultural resources also figured prominently in the team's findings. One item in their report dealt with the need to increase interpretation of cultural resources for the public. Another item dealt with the need to assess research requirements in the cultural resource management program. The team's findings in this area were as follows.

> Cultural resources are a major aspect of land management in Region 3. Plans and programs for cultural resource inventory, protection, restoration, and public interpretation are being developed. Forest Service research has historically not included programs on cultural resources research. Consequently little work has been done in identifying research needs in this area, if they exist. Programs in universities may be adequate, but it is likely they emphasize archeological aspects of cultural resources not land management considerations.[5]

In the action plan developed pursuant to the review report, the Region and Rocky Mountain Station agreed to analyze the need for a Forest Service cultural resources research program in the Southwest. This analysis would be done through a symposium addressing the topic, co-sponsored by the Region and the Station. The Station would then determine the need for such a program based on the symposium's findings and recommendations.

Planning for the symposium began in mid-summer of 1987. The planning team assembled for this purpose included representatives from the Southwestern Region and Rocky Mountain Station, and individuals from several other agencies: the Bureau of Land Management, the National Park Service, the Bureau of Indian Affairs, the Corps of Engineers, and the New Mexico Historic Preservation Division.[6] Joseph Tainter of the Cibola National Forest was designated Symposium Coordinator.

One of the first tasks of the planning team was to define the objectives of the symposium. These were derived from the Southwestern Region's overall statement of purpose (Muniz, this volume), and from the goals of the Region's cultural resource management program. The objectives of the symposium were to identify and prioritize research needed to:

1. Provide quality, on-the-ground management of cultural resources in the Southwestern Region.

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[1] Paper prepared to introduce the Forest Service Cultural Resources Research Symposium [Grand Canyon, May 2 - 6, 1988].

[2] Judith G. Propper, Regional Archeologist, USDA Forest Service, Southwestern Region, Albuquerque, NM.

[3] Joseph A. Tainter, Archeologist, USDA Forest Service, Cibola National Forest, Albuquerque, NM.

[4] The review team members were Jeff M. Sirmon (Deputy Chief, Programs and Legislation), Sotero Muniz (Regional Forester, Southwestern Region), Charles Loveless (Station Director, Rocky Mountain Station), Charles W. Philpot (Associate Deputy Chief, Research), Rex Hartgraves (Associate Deputy Chief, Administration), Larry D. Henson (Associate Deputy Chief, National Forest System), and John W. Mumma (Staff Assistant to Deputy Chief, Programs and Legislation).

[5] U.S. Department of Agriculture, Forest Service. 1986. General Management Review, August 20-29, 1986, Southwestern Region and Rocky Mountain Forest and Range Experiment Station. USDA Forest Service, Washington, D.C.

[6] The planning team members were Ken Bowman, Robert Hamre, Linda Lux, Peter Pilles, Judith Propper, Joseph Tainter, and Robert Tippeconnic for the Forest Service; Stephen Fosberg for the Bureau of Land Management; Jim O'Hara for the New Mexico Historic Preservation Division; Larry Nordby, Pete McKenna, and Joseph Sanchez for the National Park Service; Beth O'Leary and John Schelberg for the Corps of Engineers; and Bruce Harrill for the Bureau of Indian Affairs.

2. Facilitate management of other resources.

3. Provide service to the public in the following areas:

A. Contribute to the scientific understanding of Southwestern history and prehistory.

B. Develop knowledge of the past that will help avoid or solve contemporary problems.

C. Interpret the past for the public and, through education, encourage cultural resource appreciation and protection.

D. Strengthen relationships with, and promote understanding and appreciation of, contemporary cultural groups that have links to the past.

With these objectives established, the planning group asked the National Forests in the Southwestern Region, and other agencies and parties, to suggest research needs in cultural resource management. Over 50 topics were suggested, which indicated both that there was great interest in our efforts, and also that there is important research to be done in this area. After much analysis and discussion, the planning group consolidated these individual items into eight topical areas, around which the symposium was organized. These are:

1. Management Impacts. Do we understand how various management practices and land uses actually affect cultural resources?

2. Native American Heritage. Do we have adequate knowledge about how Native Americans view and use National Forest lands?

3. Protection and Preservation. How can we better protect cultural resources from loss due to pothunting, vandalism, and natural forces?

4. Site Discovery and Definition. How reliable are various inventory techniques and strategies for locating and accurately characterizing cultural remains?

5. Public Interpretation and Education. Do we know what Forest visitors want to learn about the past and what interpretive approaches and techniques are most effective?

6. Key Prehistoric Research. In order to move forward in the study of prehistory in the Southwest, what are our most critical research needs?

7. Key Historic Research. In what areas is research needed to help us understand and manage historic period resources?

8. Integrated Research Designs. Can regional research designs and coordinated efforts provide a more effective framework for cultural resource management in the Southwest?

Persons with expertise or interest in each of these areas were proposed, and invited to participate in the symposium. Eventually 57 individuals were able to attend. Several were asked to bring prepared papers to present to the symposium group the first day; these papers were to serve as a basis for further discussion. (The first-day presentations are denoted by an asterisk in the Contents.) Other participants were asked to lead or serve on work groups which would meet throughout the rest of the week, and which would collectively produce papers summarizing their conclusions and recommendations.[7] Following presentation of all work group results, participants on the last day were asked to prioritize the array of research needs, a difficult task. The results of the work groups are summarized in a later paper (Management Summary and Recommendations), along with the recommended priorities.

The conference participants were a dedicated and hard-working group. They generously agreed to give the time and effort to participate, and persisted through computer problems, organizational changes, and barbeques in freezing windstorms. They have collectively produced a fine set of research topics for the agency to consider. We appreciate and commend their work. The work group members and team leaders were as follows.

Management Impacts. Patricia Spoerl, Coronado NF (leader); Stephen Fosberg, BLM-New Mexico State Office; Joseph Gallagher, Boise NF; Ken Wilson, Six Rivers NF; Tom Lincoln, Bureau of Reclamation (Phoenix); Jon Young, Carson NF.

Native American Heritage. E. Charles Adams, Arizona State Museum (leader); Peter Pilles, Coconino NF; Edmund Ladd, Laboratory of Anthropology, Museum of New Mexico; Terry Leonard, Salt River Indian Community; Sonia Tamez, FS, Pacific Southwest Region; Elizabeth Brandt, Arizona State University.

Protection and Preservation. Martin McAllister, Archaeological Resource Investigations (leader); Mike Taylor, New Mexico State Monuments; Larry Nordby, NPS, Southwest Cultural Resources Center; Judith Propper, FS, Southwestern Region; Chris Christensen, Pacific Northwest Research Station; Dale McCormick, FS, Southwestern Region; Ken Mabery, NPS, Southwest Cultural Resources Center.

Site Discovery and Definition. Alan Sullivan, University of Arizona (leader); Luann Wandsnider, Cibola NF; Paul Fish, Arizona State Museum; Carl Phagan, Northern Arizona University; Mark Calamia, BLM-Carlsbad; Bruce Donaldson, Apache-Sitgreaves NFs; John Hanson, Kaibab NF; Emily Garber, Cibola NF; Susana Katz, Center for American Archeology.

[7] We are grateful to James Snyder of the Cibola National Forest for assembling and disassembling the personal computers on which the conference papers were written. We express our appreciation also to Ann Baugh and the other staff members of the National Park Service Albright Employee Development Center, where the symposium was held, for their help and hospitality.

Public Interpretation and Education. Chuck McCurdy, retired NPS (leader); Paul Katz, Center for American Archeology; Linda Kelley, Tonto NF; Gary Stumpf, BLM-Arizona State Office; Diane Gelburd, Soil Conservation Service, Washington; Anne Baldwin, Coconino NF.

Key Prehistoric Research. Steadman Upham, New Mexico State University (leader); Jeffrey Dean, Laboratory of Tree-Ring Research, University of Arizona; Patricia Crown, Southern Methodist University; Thomas Cartledge, Santa Fe NF; Suzanne Fish, Arizona State Museum; David Johnson, Lincoln NF.

Key Historic Research. Joseph Sanchez, NPS, Spanish Colonial Research Center (leader); George Teague, NPS, Western Archeological and Conservation Center; James Rock, Klamath NF; David Brugge, NPS, Southwest Cultural Resources Center; David Siegel, US Fish and Wildlife Service, Albuquerque; Scott Wood, Tonto NF.

Integrated Research Designs. Joseph Tainter, Cibola NF (leader); Linda Lux, FS, Pacific Southwest Region; David Wilcox, Museum of Northern Arizona; Evan DeBloois, FS, Washington; Shereen Lerner, Arizona SHPO; John Schelberg, Corps of Engineers, Albuquerque.

The conference benefitted also from the participation of Forest Service line officers and Research Station representatives. We were joined by Sotero Muniz (Regional Forester, Southwestern Region), David Jolly (Deputy Regional Forester, Southwestern Region), Enoch Bell (Assistant Director, Pacific Southwest Forest and Range Experiment Station), Ed Wicker (Assistant Director, Rocky Mountain Forest and Range Experiment Station), and Robert Hamre (Technical Publications Editor, Rocky Mountain Forest and Range Experiment Station).

All papers prepared before and during the conference are included in this volume. There is much to choose from here: the topics range from public interpretation to site protection, from designing coordinated research to actually implementing it. A number of important management recommendatons also emerged during work group deliberations and are included for agency consideration. The papers represent the best wisdom available on what research the agency needs to do, and at the same time are a good cross-section of contemporary concerns in archeology and cultural resource management. There is much work to be done, all of it important, and most of it urgent.

Research is a creative process, not only in finding solutions to problems, but also because in finding answers we discover new questions. If at some future time another symposium like this is convened, our progress as managers and scientists will be measured by how many of these topics we have successfully addressed, and by how many new questions have subsequently arisen.

What Forest Managers Need to do a Better Job of Managing Cultural Resources[1]

Sotero Muniz[2]

INTRODUCTION

It's heartening to see such a diverse representation of scientists from so many organizations and agencies that will be working with us this week. And I'd also like to express appreciation to the National Park Service for hosting us this week in Grand Canyon at the Albright Training Center. We view the Park Service as a sister agency. We routinely coordinate activities and provide mutual support.

In the Southwestern Region of the Forest Service we have a simple one-sentence statement of organizational purpose. This statement literally guides everything we do. It is, "We exist to provide quality, on-the-ground resource management, protection, and public service." We can link the events of this week to this statement by inserting the word "cultural". What we are about this week, then, is to increase our effectiveness in "providing quality, on-the-ground CULTURAL resource management, protection, and public service."

I encourage each of you to contribute to this symposium unfettered by a need to protect us from hurt feelings. We need and can benefit from your critiques. If you disagree with our orientation, or our actions, tell us! If you have better ways for us to meet our objectives, help us to understand that there are better ways. Your counsel and critiques can help us do better. We will try hard to listen and hear what you have to say.

Dr. Ed Wicker and others are here representing the Research arm of the Forest Service. Ed will address you next and share his thoughts and expectations from this symposium with you. Suffice it to say that we in the National Forest System acknowledge the need for integrated cultural resource management research. Clarifying these research needs and some stratification by priority are key components of this symposium for me.

We have a diverse representation of archeologists, historians, and scientists in attendance. Universities in Arizona, New Mexico, and Texas are represented. A State Historic Preservation Officer is here. Archeologists representing State Museums, State Monuments, the Center for American Archeology, the Laboratory of Anthropology, and private consultants have joined us. USDI's National Park Service, Bureau of Land Management, and Fish and Wildlife Service are represented, as is the Soil Conservation Service from USDA. On the Forest Service side, three Research Stations, the California Region, and our Chief's Office join those of us from the Southwestern Region. A warm Region 3 welcome to all of you!

This impressive assemblage of talent speaks well for the partnerships that do, or can, exist. Together we should be able to clarify objectives to aid us in the best selection of priority among the choices of research and management investments we have to make.

Finally, I leave you with some questions that managers like me bring to the table. I need to understand what the end results are of our efforts and investments in the management of cultural resources. Is the objective simply to protect all cultural resource properties for all time at whatever cost? Is the objective to ensure the protection of those cultural resource properties needed to enable us to chronicle the prehistory of a particular people in a particular area for a particular time period? Or, is the objective to do whatever archeological work is needed to obtain legally mandated clearance for other activities? These different objectives lead us into different management and research responses. It simply is not clear to me what our objective should be.

In my own, perhaps simplistic, view, I envision a library of some number of volumes of Southwestern prehistory, each volume containing chapters and each chapter an outline of the prehistory of the people of an area, the period of their occupancy, where they came from and where they went, and why. These volumes might also include how they lived, what they ate, what medicines they used, what social or governmental orders they developed, what records they left. In short, what was their story?

Are the end results of our cultural resource management investments and resarch the completion of individual chapters of these stories? If yes, explain it to us managers in those terms. Then we

1 Opening remarks at the symposium on Cultural Resources Research, May 2-6, 1988, Grand Canyon, Arizona.

2 Sotero Muniz is Regional Forester for the Southwestern Region of the USDA Forest Service, Albuquerque, New Mexico.

could understand that clearance actions, reports, excavations, and other CRM activities are contributing to the stories in these volumes of prehistory.

What I experience currently is requests for increased staffing and budget. The end results that I currently see are the investigation and clearance work that is mandated, and the recording of thousands of sites and properties. I don't see us systematically adding to the stories of prehistory. Hence my earlier question, "Is it our objective to protect all sites and properties, for all time, at whatever cost?"

If the "completion of stories" is the end result, I believe we managers could understand the objectives. Attitudes would then be shifted towards understanding and support.

Please be guided as appropriate by my remarks as you complete the workshops of this symposium. Thank you for listening.

Managing Cultural Resources: What Technology is Still Needed?[1]

Ed F. Wicker[2]

Good morning ladies, gentlemen, and friends. On behalf of the Rocky Mountain Station, welcome to the Cultural Resources Symposium/Workshop. I am most pleased for this opportunity to spend the week with you participating in discussions of such an important subject.

The material relics representing the cultures and land use of past civilizations are non-renewable resources that must be managed if they are to be available for the enjoyment and use of future generations. This resource base represents the major record of ancient mankind and linkage to present civilization. Understanding the history and prehistory of the nation depends to a large extent on our ability to interpret this record.

But reconstruction of the past is an inexact and time-consuming process. If we are to maintain the opportunity to improve understanding of our cultural past, it is imperative that we protect this resource from exploitation until scientists can evaluate and interpret its significance and value to reconstruction of the nation's heritage. One way to maintain this opportunity is through a positive, proactive cultural resources management program.

In the formative years of the Forest Service, the prevailing philosophy relating to cultural resources was one of preservation through protection. The Antiquities Act (1906) testifies to this position. Unfortunately, preservation through protection was perceived by most as synonymous with management. However, time proved this to be a false perception. As additional legislation dealing with cultural resources has evolved, we have seen a concurrent evolution of the philosophy to preservation of cultural resources through compliance with legislation. While progress is being made, we still have a way to go, and a concerned public is growing more impatient with Federal agencies entrusted with the responsibility to manage our heritage.

Although the concept of preservation still prevails, there are some current indications that the conservation concept is gaining momentum. Some of us believe that mere compliance with legislated mandates is inadequate to ensure conservation of our cultural resources for enjoyment and use by future generations. Thus, a positive, proactive concept is being advocated that will provide for the conservation of our cultural resources by integrating their management with other land use and resource management. The Forest Service is committed to this concept, but the knowledge, methodologies, and technologies for implementing the concept are not adequate.

To be successful in implementing this broader philosophy, some compromising is needed. Attitudes need to move more in the direction of conservation, and archeologists will need to assume a more active role in proactive management of these resources. Monitoring compliance to legislated mandates in itself is not sufficient.

Cultural resources are non-renewable resources of such value to warrant management. The Rocky Mountain Station is committed to this philosophy and supports a strong, positive, proactive cultural resources management program. We perceive our role in this commitment as providing the information and technologies needed to implement and maintain a successful proactive management program. Also, we encourage natural resource management agencies to grasp the initiative for such proactive management, and not be content with a reactive status.

Although the Forest Service has taken the lead role towards implementation of this proactive management concept, please do not view this workshop as just a Forest Service event. Most of you received a special invitation to attend because we believe you have something to contribute. Collectively, you represent 23 Federal, State, private, and native American organizations with needs and concerns relative to cultural resources management. Of equal significance, you represent a sampling of the scientific community. We want the Symposium/Workshop and its products to be perceived as a partnership effort of scientific community interests. We hope that, by the end of this week, through your contributions and interactions with other attendees, you will leave here with a feeling of commitment and ownership in the program.

Some specific objectives of this Symposium/Workshop are to determine:

a.) The goals of a proactive cultural resources management program;
b.) What knowledge and technologies are needed to implement and maintain such a program;
c.) What knowledge and technologies are already available to support such a program;
d.) What knowledge and technologies are needed, but currently unavailable.

All persons have visions. Some of us realize our visions through hard work, good fortunes, and assistance from our many friends. I hope we can engage in all these activities this week, and achieve a level of success we can look to with pride of ownership. With a diligent effort by each of us, I am certain success is imminent.

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[1] Opening remarks at the Cultural Resources Research Symposium/Workshop, May 2-6, 1988, Grand Canyon, AZ.

[2] Ed Wicker is Assistant Director for Research (South), Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, CO.

The Program: Managing Cultural Resources in the Southwestern Region[1]

Judith G. Propper[2]

Abstract.--The Southwest holds a well-preserved record of human existence going back over 10,000 years. The Forest Service's cultural resources management program in the Southwest is briefly reviewed, and a shift to a more proactive program providing greater public benefits is discussed. Research may be needed to provide National Forests with the tools necessary to fully implement this program.

INTRODUCTION

The Southwestern Region of the Forest Service consists of eleven National Forests, encompassing some 20 million acres, in Arizona, New Mexico, Oklahoma, and Texas (fig. 1). The Region is characterized by tremendous scenic and ecological diversity, stretching as it does from the deserts of southern Arizona, to the mountains and mixed conifer forests of northern New Mexico, to the rolling grasslands of the Texas panhandle. These lands are administered by the Forest Service within a multiple use management framework. Multiple use management provides for the wise use of Forest resources by the American people in a way that assures a continuing supply of these resources for future generations. Such uses include recreation, timber harvesting, grazing, mineral development, and many other types of activities.

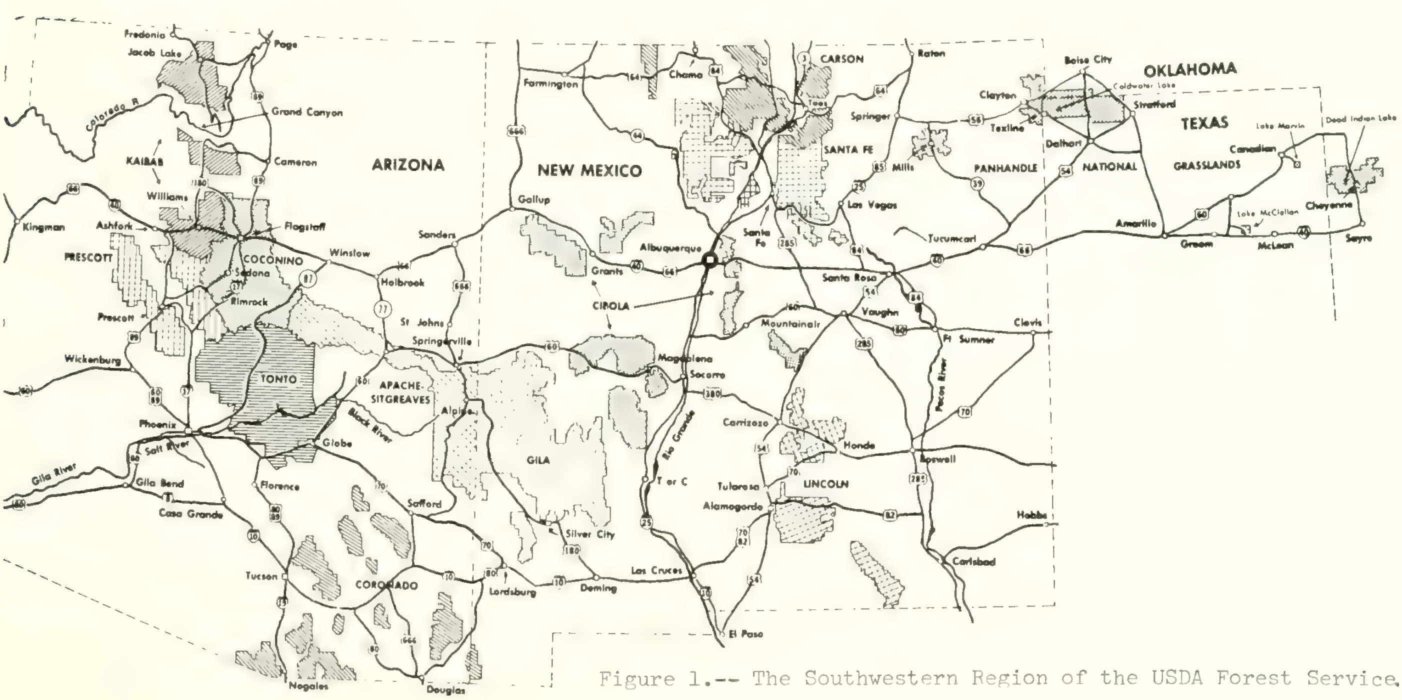

Figure 1.-- The Southwestern Region of the USDA Forest Service.

[1]Paper presented at the Forest Service Cultural Resources Research Symposium [Grand Canyon, May 2-6, 1988].

[2]Judith G. Propper is Regional Archeologist, USDA Forest Service, Southwestern Region, Albuquerque, N.M.

The Southwestern Region is well known for the richness and diversity of its cultural resources and contains what is probably the best-preserved record of human history and prehistory in the National Forest System. From picturesque cliff dwellings (fig. 2) and massive pueblo ruins, to fragile artifact scatters (fig. 3), to a myriad of historic period sites and structures (fig. 4), these resources document over 10,000 years of cultural adaptation and change.

Figure 2.--Cliff dwellings, like this one on the Prescott National Forest are found on many Forests in the Southwestern Region.

Figure 3.--Artifact scatters consisting of stone flakes and potsherds may be the only surface indications of past human activity.

All offer clues to the lifeways and events of the past, as individuals, families, and societies struggled to live successfully with the land and with each other. How they did this, and why they were successful or why they failed, has importance not only to our understanding of the past, but to our understanding of the present and our outlook for the future (fig. 5).

HISTORY OF CULTURAL RESOURCES MANAGEMENT PROGRAM

The Early Years

The Forest Service, like most other Federal land-managing agencies, established a formal program to protect and manage cultural resources in the late 1960's, following passage of the National Historic Preservation Act (1966). The Southwestern Region hired its first professional archeologist to coordinate this program in 1973. The 1970's were years of slow but steady growth, as national and Regional policies were formulated, and Forests developed the mechanisms to deal with the basics of legal compliance. By the early 1980's, there were professional archeologists on most Forests in the Region, and cultural resources routinely were given consideration in planning and implementing land management activities.

The major focus of the program was on project compliance, specifically field surveys to locate cultural resource sites in advance of earth-disturbing projects (fig. 6). In most cases, once located, sites could be protected through avoidance during project activities. The main outputs of the program were acres surveyed and sites located, and file drawers swelled with the accumulation of survey reports and site forms. Once located, sites were rarely revisited or investigated, and knowledge about these resources was usually limited to surface observations made during surveys.

During these years, the Region also took a number of pioneering steps to try to address broader program needs. In cooperation with the Bureau of Land Management, an initiative was begun

Figure 4.--Remains of historic cabins, found throughout the Southwestern Region, hold clues to early settlement, mining, and logging.

Figure 5.--Continuity between past and present is evident in many contemporary Native American communities in the Southwest.

to assemble and synthesize known archeological and historical data in a series of cultural resource overviews. The Region also organized several symposia to deal with such topics as predictive modeling (Cordell and Green, 1984) and site allocation (Green and Plog, 1983). Vividly aware of the destruction of cultural resources on public lands due to pothunting, the Region took the lead in efforts to bring archeologists, law enforcement officers, and legal experts together to work on this problem (Green and Davis, 1981).

On most Forests, however, the situation on the ground remained one of primarily reacting to the needs of other resource management programs and activities. Cultural resources were basically a procedural hoop in the project planning process.

Figure 6.--Field surveys to locate and record cultural remains have long been a major component of Forest cultural resource management programs.

A Time of Transition

The mid-1980's have been a time of reassessment of the Region's cultural resource management program. One result has been a strengthening of existing standards to provide better site protection. A more important result, however, has been a redefining of basic program content to include more than compliance activities.

A number of factors have been involved in bringing about this reassessment. One is the development, over the past several years, of Forest Land Management Plans. This process, which is ongoing, requires specific consideration of cultural resources and has provided new opportunities to identify priorities for non-project related cultural resource inventory, evaluation, protection, and enhancement.

Another important factor is the increasing public interest and involvement in the management of cultural resources in the Southwestern Region, including a cultural resources lawsuit in 1984. This interest has helped focus attention on the need not only to assure better on-the-ground management, but to provide greater benefits to the public in the cultural resources program.

Finally, there has been a growing frustation on the part of National Forest land managers and archeologists alike over the program's reactive nature, compliance orientation, and survey-and-avoid mode of operation. After surveying some two million acres, and recording over 20,000 sites, only around 1 per cent of those sites have been evaluated, and only a handful are currently interpreted in some way for the public. Concern over this helped create a responsiveness at all levels to the idea of redefining the program's emphasis and scope.

The end result has been a gradual adjustment in thinking about the Region's short-term as well as long-term cultural resource management goals. This has led to recognition of a broader range of priorities in the program and a committment to get on with the larger job.

MOVING INTO THE FUTURE

A Proactive Program

As we prepare to enter the 1990's, the Southwestern Region is committed to continued implementation of a balanced, proactive (rather than reactive) cultural resources management program. While legal compliance continues to be a major element in this program, it is but one aspect of our overall responsibilities as stewards and managers of the nation's cultural heritage.

The basic components of this program include the following:

1. Inventory: An expanded inventory program, addressing areas other than project locations. The

Figure 7.--Pothunters have plundered many prehistoric sites on public lands in search of artifacts to sell or display.

goal is to provide a more complete picture and a better understanding of the distribution of cultural resources across the Forest landscape.

2. Evaluation: Studies aimed understanding inventoried cultural resources, including the nature of individual sites, the relationships between sites, and the interaction between cultural and natural systems. Only through such understanding can we deal meaningfully with questions of significance and make wise decisions about what to preserve for future generations.

3. Protection: Effective site protection efforts aimed at minimizing the loss of important cultural resources due to natural deterioration, public use, vandalism, and theft (figs. 7 and 8). This will require an understanding of causes as well as effects in arriving at appropriate courses of action and will require a long term committment to protection and stabilization objectives.

4. Allocation: A program of site allocation that takes into account the special scientific, cultural, interpretive, and management-related values of cultural resources in making decisions about the use of these resources. Allocation is based on a recognition that avoidance of all sites forever is not management, but is merely an expedient practice that contributes little to our understanding of the past.

5. Interpretation: An emphasis on cultural resource interpretation and public outreach that provides opportunities for Forest visitors and local communities to learn about Southwestern history and prehistory (fig. 9). Such efforts will also contribute to the understanding and preservation of Native American cultures and other traditional cultures in the Region.

Figure 8.--Time is taking its toll on many sites threatened by deterioration and erosion.

6. Integration with Forest Resource Management: Consideration of cultural resources as a resource in the early planning stages of land management activities (fig. 10). This includes consideration of cultural resource management objectives along with other objectives. Legal compliance will be a logical by-product of this process, rather than its primary goal.

7. Partnerships: Expansion of partnerships with local communities, Native Americans, other agencies, the scientific community, and others in a coordinated effort to further the study, understanding, and preservation of cultural

Figure 9.--National Forests and other public lands in the Southwest provide unique opportunities for visitors to discover the past.

Figure 10.--Managing cultural resources as a resource presents both challenges and opportunities for Forest managers.

resources in the Southwest. Such cooperation will significantly increase the effectiveness of many individual efforts.

The Tools to Do the Job

In order to more fully implement the cultural resources management program outlined above, we may need knowledge and technologies not presently available to us. The objectives of this symposium are to determine if this is the case, and if so, to identify priorities for research that will help us move forward in this program.

Cultural resources hold the keys to the story of human life in the Southwest beyond what exists in our collective memory and in our writings (fig. 11). The study and preservation of this record of the past deserves our utmost care and our highest standards of scientific and managerial excellence. That makes this consideration of research needs a matter of great importance and great excitement.

Figure 11.--Like pieces of a puzzle, cultural resources hold clues to the larger story of human life in the Southwest and the region's remarkable cultural developments.

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Management Summary and Recommendations[1]

Joseph A. Tainter[2]

INTRODUCTION

From May 2 - 6, 1988, 57 archeologists, Native Americans, and managers met at the Grand Canyon to evaluate the need for a program of cultural resources research. The proposed program would be based in the Rocky Mountain Forest and Range Experiment Station, and concentrate on research in the Forest Service Southwestern Region. The objectives of the symposium were to identify and prioritize research needed to:

1. Provide quality, on-the-ground management of cultural resources in the Southwestern Region.

2. Facilitate management of other resources.

3. Provide service to the public in the following areas.

A. Contribute to the scientific understanding of Southwestern history and prehistory.

B. Develop knowledge of the past that will help avoid or solve contemporary problems.

C. Interpret the past for the public and, through education, encourage cultural resource appreciation and protection.

D. Strengthen relationships with, and promote understanding and appreciation of, contemporary cultural groups that have links to the past.

Although the symposium concentrated on the Southwest, many of the research topics that were identified are of national importance, and would be of interest to other Federal agencies that manage cultural resources. The participants determined that there is unquestionably a need for a program of cultural resources research in the Forest Service.

Planning prior to the symposium identified eight broad topics for organizing the conference. These were:

1. Management Impacts.

2. Native American Heritage.

3. Protection and Preservation.

4. Site Discovery and Definition.

5. Public Interpretation and Education.

6. Key Prehistoric Research.

7. Key Historic Research.

8. Integrated Research Designs.

Leading experts in these areas were invited to prepare state-of-the-art syntheses for presentation on the first day of the meeting. These presentations were to review current knowledge of a topic, and to point out areas that need further research.

The participants divided into eight work groups for the bulk of the week. The group members discussed the matters raised in the initial presentations, and developed recommendations for further Forest Service research. Each group also selected one topic as its highest priority. This would be the topic most urgently requiring attention, although the groups felt that the research branch should at some point study all the topics outlined.

The problem-areas and research topics delineated by the working groups are described in the following sections.

MANAGEMENT IMPACTS

Research Needs

- Although there have been some good studies, we still know little about how management activities and land use affect sites. We also know little about what level of disturbance will affect the information potential of a site.

- Managers need to understand secondary impacts to sites. These are impacts that result indirectly from land uses, but which may ultimately be more serious than direct impacts. Secondary impacts may arise from human use (increased accessibility and visibility) or from unforeseen physical consequences (e.g., changes in cattle trampling patterns, or subsurface changes in site structure after surface seeding).

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[1] Paper prepared to summarize the Forest Service Cultural Resources Research Symposium [Grand Canyon, May 2 - 6, 1988].

[2] Joseph A. Tainter, Archeologist, USDA Forest Service, Cibola National Forest, Albuquerque, N.M.

- Managers need to know whether current techniques of avoiding site impacts are effective.

- The effects of natural processes on sites (e.g., fire, erosion) are little known.

Research Recommendations

Highest Priority

- Study secondary impacts to sites - impacts caused by management and land use, but occurring as an indirect effect.

Other High Priority Topics

- Prepare an overview of existing impacts research to isolate research needs systematically, and to assess what technology is needed to implement a research program.

- Begin a program of on-the-ground impacts research, using defined study areas on National Forests.

NATIVE AMERICAN HERITAGE

Management Problems

- Relations between Forests and tribes tend to be institutional rather than personal. Personal contacts are much more effective when dealing with Native Americans.

- Forests often have no program of consulting Native American communities, and no staff person skilled in Native relations.

- Forests lack up-to-date information on how Native people use the Forests.

Management Recommendations

Although the members of the Native American Heritage group developed a research program for the Forest Service to consider, they felt that the research was not necessary. Their conclusion was that the steps needed to improve relations with Native Americans are already known. These steps could be implemented by the Southwestern Region (and by other Regions) without further research. This group recommended the following management actions:

- Cooperate with Native tribes to have the tribes produce up-to-date ethnographies of their Forest uses.

- Retain the services of anthropologists skilled in Native American relations. To guide Forests in improving Native relations, establish the position of Regional Ethnologist. Forests may also wish to establish liaisons to coordinate Forest-tribal relations.

PROTECTION AND PRESERVATION

Research Needs

- To curtail looting managers need to understand the motivations and perceptions of looters, and the other factors that lead people to dig for artifacts. A related matter is to understand the public attitude toward looting.

- Managers and law enforcement officials need to understand the national and international networks for distributing illegally-obtained artifacts.

- The factors that make certain sites at high risk are inadequately known.

- Baseline data need to be gathered on the extent and distribution of looting, and on the level of cultural resources law enforcement.

- There is a need to develop, and test the effectiveness of, cultural resources law enforcement training and site protection programs.

- Little is known about the effectiveness of techniques and materials used to stabilize sites.

Research Recommendations

This group split into two subgroups, one concerned with protecting sites from looters, the other concerned with preserving sites subject to natural deterioration.

Protection Subgroup. The research recommended by the members of the protection subgroup - as their only priority - is an overall assessment of cultural resources vulnerability. It consists of the following elements.

1. Study cultural resources data bases to determine the characteristics of vulnerable sites. Develop a site-vulnerability profile.

2. Ascertain public attitudes toward cultural resources management and looting.

3. Determine the motivations for cultural resources theft and defacement.

4. Develop effective protection strategies.

Preservation Subgroup. The preservation subgroup recommended a program of research into the technology of prehistoric and historic building stabilization. This program is as follows.

Highest Priority

- o Develop an understanding of the physical properties of original building materials.

Other High Priority Topics

- o Determine the effectiveness of current stabilization methods, and develop new and more efficient techniques.

- o Study original building methods to understand the technologies and cultural values of prehistoric and historic construction.

SITE DISCOVERY AND DEFINITION

Research Needs

- o Managers need to understand the nature of the archeological record. Cultural resources concepts mandated by laws, regulations, and agency practices may be incompatible with the actual nature of archeological remains. The proper unit of research and management may not be sites but past cultural landscapes. Management emphasis on sites may bias the record of past behavior that is preserved.

- o Managers need to know what technology - such as Geographic Information Systems (GIS) - will assist in the inventory and management of low- and high-density archeological remains.

Research Recommendations

Highest Priority

- o Determine which survey methods and technologies are most effective for discovering archeological remains at different levels of visibility.

Other High Priority Topics

- o Determine the optimum spatial units of description and analysis for different kinds of cultural remains.

- o Develop methods such as GIS systems for locating and recording environmental features that influenced the locations of past activities.

This group also recommended that parcels of National Forest land be temporarily set aside to conduct the proposed research.

PUBLIC INTERPRETATION AND EDUCATION

Research Needs

- o Managers need detailed information on what constitutes effective cultural resources interpretation.

- o Interpretation specialists need to determine educational needs in cultural resources, and to identify target audiences.

Research Recommendations

The members of the Public Interpretation and Education group identified as their only priority a two-part research program. The two elements are as follows.

1. Compile, synthesize, and evaluate existing literature pertinent to cultural resources interpretation.

2. Develop a user profile that will allow cultural resources interpretation to be keyed to visitor needs.

KEY PREHISTORIC RESEARCH

Research Needs

- o Progress in understanding and interpreting prehistoric sites must come from the study of key research themes. These include studies in such matters as agriculture, social and political organization, demography, settlement, labor, economics, and past environments. The ultimate purpose of such studies is to understand why societies develop and collapse.

- o The investigation of key research themes requires basic studies in such topics as past climates and environments, the distribution of raw materials, the dating of sites, and the ways in which the archeological record is formed.

Research Recommendations

The members of the Key Prehistoric Research group picked one topic - the development of reliable chronologies - as their only priority. It has three parts.

1. Develop a program to refine methods of dating prehistoric sites (e.g., by obsidian hydration, archaeomagnetism, or accelerator-mass spectrometer).

2. Develop and maintain a master data file of archeological and environmental information pertinent to questions of chronology. Use this data file to develop chronologies for localities, Forests, and the Region.

3. Develop a program to identify, retrieve, and conserve datable archeological materials, and to date such materials.

The reason for this research emphasis is that all questions of cultural resources management and research depend on an ability to determine the age of archeological materials.

KEY HISTORIC RESEARCH

Research Needs

- Cultural resource managers need to bring to public attention the Hispanic contribution to the nation's heritage. The Columbus Quincentennial provides an opportunity to study the Spanish Colonial occupation of the Southwest.

- Managers need research that will encourage public respect for cultural resources. There is great public interest in the historic settlement of the nation, and in early economic activities such as logging, mining, railroading, and ranching. Research and interpretation in these topics would generate public support.

- Progress in understanding and interpreting historic sites must come from the study of key historic themes. These include major topics such as assimilation, ethnicity, status, settlement, and subsistence. To understand key research themes requires fundamental research on techniques of study, taxonomies, and chronologies.

Research Recommendations

The Key Historic Research group recommended that the Forest Service create a Research Work Unit to conduct historical studies. These studies would benefit cultural resource management, general forest management, and public interpretation. The Research Work Unit would concentrate on the following topics.

Highest Priority

- Study Spanish Colonial history for the 1992 Columbus Quincentennial.

Other High Priority Topics

- Study late nineteenth and early twentieth century Native American use of Forest lands.

- Study Forest Service historical buildings.

- Study historical mining on Forest lands.

INTEGRATED RESEARCH DESIGNS

Research Needs

- The National Register eligibility criteria provide little guidance for evaluating sites. Sites are typically evaluated on a case-by-case basis, without a comparative perspective or a broad plan.

- Most National Forests lack a decision-support system for cultural resources data.

- Archeologists in Forest management often lack access to new technical and conceptual developments in the discipline.

- Cultural resource management in the Forest Service has been reactive: oriented toward legal compliance rather than active management. Managers need research aimed at anticipating and resolving resource conflicts.

- There is widespread misunderstanding of the dynamic nature of archeology as a social science, and of the challenge that this poses for long-term planning. Managers need research that will provide guidance for making long-term preservation decisions.

Research Recommendations

Highest Priority

- Evaluate existing cultural resources decision-support systems (data bases), and if necessary develop a new one that will allow managers and researchers to access cultural resources information readily.

Other High Priority Topics

- The Forest Service should coordinate a program of integrated research that incorporates Federal agencies, State Historic Preservation Offices, and non-government archeologists.

- Forest Service Research should develop a program to transfer new cultural resources knowledge and technology to on-the-ground management.

SYMPOSIUM RECOMMENDATION

On the final morning of the conference all participants met to discuss which of the highest-priority research topics should be started first. This decision was concerned with matters of urgency rather than importance: the participants agreed that all of the research topics are important, and the major question is what work to begin with.

A period of discussion on this matter led to a consensus on what research should be started first. This consensus was then confirmed by a formal vote. The recommendation of the conference was that the Forest Service initiate research on the following.

1. Protection and preservation of sites. Develop effective strategies of site protection and stabilization. Assess the vulnerability of cultural resources to vandalism, and conduct studies to understand the physical properties of ancient building materials.

2. Management impacts. Assess secondary impacts of land use and land management, to determine if current methods of site avoidance are providing adequate protection.

3. Decision-support systems. Evaluate existing cultural resources data base systems. If necessary, design a new one, based on Geographic Information Systems, that will give managers accurate information on the location and nature of cultural resources.

The remaining highest-priority topics from each work group were not assigned an overall order of priority, but their ranking in the formal vote was as follows: prehistoric chronology, testing alternative survey methods, Spanish Colonial research, and interpretive programs research. The recommendations of the Native American Heritage group can be put into place without further research. Although this topic does not seem to require immediate research, the participants ranked the group's recommendations quite highly.

CONCLUSION

As the Southwestern Region develops a positive program of cultural resource management - emphasizing scientific, cultural, and recreational values - we are finding that we lack many of the tools necessary to evaluate sites, to protect them, even to determine their age. The research recommended at the conference reflects the combined efforts of leading cultural resource specialists. This research is essential if we are to understand, protect, and interpret the unique heritage of the Southwest.

Management Impacts on Cultural Resources: an Assessment of Forest Service Research Needs[1]

Patricia M. Spoerl[2]

Experimental research regarding the cultural processes which impact archaeological resources is summarized and evaluated. Impact categories considered include land management (project) impacts, human (recreational) impacts, survey identification impacts, and agency impacts. Recommendations are made for Forest Service research needs regarding management impacts.

INTRODUCTION

"The study of impacts on archaeological resources can provide a scientific, theoretical, and methodological underpinning for the future of our profession." (Leslie Wildesen 1982:83)

"The archaeological record is not a safe haven for artifacts." (Michael Schiffer 1987:121)

When I began working for the Forest Service, I was told that the Forest Service did not do archaeological research. We also did not do much management although it was stated that management was the overall goal of the cultural resources program. Instead, we operated mainly in a compliance mode, with notable but sporadic attempts to really "manage" the resource. Site avoidance was practiced whenever possible; however, people seldom returned to these sites to determine if they really had sustained no impacts from project work.

Our cultural resources program has been changing rapidly in recent years with considerable effort expended upon implementing a comprehensive management program for prehistoric and historic resources. It has become quite apparent, however that the Forest Service can not really manage cultural resources without appropriate research to determine optimal strategies for site specific as well as overall treatment of the resource.

[1]Paper presented at the symposium on Tools to Manage the Past: Research Priorities for Cultural Resources Management in the Southwest. [Grand Canyon National Park, Az. May 2-6, 1988].

[2]Dr. Patricia Spoerl is Forest Archaeologist on the Coronado National Forest, Tucson, Az.

This paper deals with cultural resources management in relation to management of other forest resources. Forest Service management activities affect cultural resources in varying degrees. Logging operations impact sites and artifacts, cattle trampling can affect the spatial distribution and quantity of materials at a site, fire suppression efforts may obliterate sites, and a host of other activities which are part of multiple use management affect the forests' cultural resources.

The Forest Service has been conducting archaeological surveys routinely for almost 15 years now and around 25,000 sites have been recorded on the forests of Arizona and New Mexico. Very little excavation has been conducted, thus the vast majority of our assessments, evaluations, management strategies, and clearance recommendations are based upon archaeological data observable on the ground surface. Under ideal conditions, the kinds of archaeological materials and features, and their distribution on the surface, should reflect the ways in which prehistoric peoples used the land and its resources, as well as a site's depositional and erosional history. Distortion or destruction of this context limits our attempts to identify patterns in the archaeological record. Therefore, knowledge of the extent to which site surfaces have been modified is essential to reliable and accurate archaeological inference.

We do know that the archaeological record is not a static phenomenon. Sites have been subjected to a variety of natural and cultural processes that affect the ways in which artifacts and features are spatially distributed. Often termed formation processes (Schiffer 1976, 1987), natural or environmental processes consist of the postdepositional changes in site and artifact morphology caused by natural factors such as wind, water and erosion, while cultural processes are those where human actions affect the material

record. It is the cultural processes which form the focus of this paper.

THE PROBLEM

The purpose of this paper is to summarize and evaluate current knowledge regarding the kinds of management impacts that affect archaeological sites. Historic sites are included by implication, however most studies have focused on prehistoric sites and artifacts. A review of experimental studies involving impacts to archaeological sites was published in 1982 by Leslie Wildesen, then a Forest Service archaeologist. The recommendations made regarding future research needs are, for the most part, still valid. Fred Plog in "Managing Archeology" (1981) prepared for the Apache-Sitgreaves National Forests, addressed the need for evaluation of impacts of Forest Service activities on archaeological sites, as did McGuire and Schiffer (1983) in an overview of southwestern Arizona. A proposal to the National Science Foundation prepared in 1982 by Forest Service and New Mexico State University personnel (Upham and Green 1982) requested funding for a series of experiments on the Lincoln and Santa Fe National Forests to 1) determine the effects on archaeological sites of management and recreational activities, and 2) to measure errors in observer (i.e. archaeologists) biases that occur during site surveys and surface collections. The proposal was not funded.

The experimental work which has been completed has been on an individual site or project specific basis. Limited progress has been made in terms of understanding the factors which impact sites. We still, however, lack sufficient empirically-based data regarding what happens to archaeological resources as a result of various ground-disturbing activities, and we also lack an integrated research program with which to investigate these management impacts.

Let's look briefly at definitions. Impact is defined by Wildesen (1982:53) as "a measurable change in a chacteristic or property of an archaeological site". Schiffer (1987:121) has recently termed similar measurable changes "disturbance processes". He notes that disturbance "usually results from an activity that has another purpose; artifacts and deposits just happen to be modified or moved along the way." Impact is, however, not synonymous with damage. Damage involves changes in an archaeological site but also includes a professional judgement regarding loss of significant information. Such judgements are not applied in determining impacts. Rather they come from evaluating the impacts to determine what effects they will have on our interpretations of the archaeological record.

Impacts are determined by observation, measurement, and description. Impacts to artifacts can be measured in several ways: alteration of an artifact through compositional changes, breakage, vertical and horizontal displacement, and loss or removal from the archaeological record. Impacts may either be direct or indirect. Direct impacts are caused by an action and occur at the same time and place while indirect impacts are caused by an action and occur later in time or farther removed in space (Council on Environmental Quality 1978). Schiffer (1987:23) relates impacts to four types of variability in archaeological materials: 1) the formal dimension involving physio-chemical properties of artifacts, 2) spatial relationships of artifacts, 3) frequency of artifacts and artifact types, and 4) relational patterns of artifacts.

There are a number of ways to classify impacts. For purposes here, cultural processes are subdivided in four categories: land management (project) impacts, human (recreational) impacts, survey identification impacts, and agency impacts. Not all known studies of each type are included here; rather, the objective is to summarize the different kinds of studies which have been conducted.

CULTURAL PROCESSES STUDIES

Land Management Impacts

Management impacts include those which result from Forest Service or Forest Service authorized ground disturbing actions. Timber and fuelwood harvest are perhaps the most often referred to activities which impact sites. The effects of yarding operations on archaeological sites have been investigated in several studies. On forests in Oregon and Washington the effects of various types of yarding operations (e.g. tractors on bare ground, and cable logging on mild and steep slopes) were measured on artificially constructed lithic scatter sites (Bryant, Gehr and Flenniken 1982). A variety of problems occurred involving scheduling, sales which did not sell, and severe weather conditions which hindered the quality and quantity of results. A similar study in eastern Oregon (Phillips 1980) found differential artifact movement on different parts of a site and in different soil types.

The impacts to sites of logging over snow have been investigated in a number of places including, in this Region, on the Coconino National Forest. The most comprehensive study was completed in 1984 in Oregon where the impacts to two large lithic scatters were measured (Philipek 1985). Artifact displacement, loss and breakage were considered minimal in over-snow logging with sufficient snow depth, low temperatures and short duration of operations.

Impacts to sites from scarification, the process of mechanically loosening top soil in preparation for regenerating a timber stand, have been examined in Idaho by Gallagher (1978). He

placed 396 steel washers in 99 postholes up to 6 inches deepand found that fourteen percent of the washers were horizontally displaced, 5 percent were vertically displaced, and 36 percent were lost (and not found even using a metal detector).

DeBloois, et al. (1975) examined impacts of pinyon-juniper chaining, that is the uprooting of unwanted trees using mechanical equipment and long chains. In their study, 367 artifacts were placed in test squares. Only 53 percent of the artifacts could be relocated, and approximately one third of these were undistrubed. Hoase (1983) examined the types of sites most susceptible to adverse impacts from chaining as well as methods for reducing or eliminating its disruptive effects. Given the severe impact to small and shallow sites, he proposes a method for protecting sites by creating islands of unchained areas (1983:160).

Cattle trampling, trailing, and grazing can impact archaeological materials, and there are examples of cattle impacting historic standing structures by rubbing. Several studies have been initiated. In one, Roney (1977) concluded that horizontal displacement of artifacts by cows was less severe than commonly assumed although almost half the artifacts used were damaged and 95% of them disappeared from the surface inventory as a result of intensive trampling. In another, Logsdon (1976) established 2 meter^2 test plots in a cow pasture near Casper, Texas. After 50 days in the pasture, only 193 of the 242 flakes were recovered. Eighty-one (42%) of these had been damaged through breakage and fractures.

Cattle trampling, as well as trampling by other animals and humans, generally occurs in patterned ways by creating definite path (or trail) and non-path areas. Experiments on the effects of trampling have been conducted by archaeologists in diverse geographic locales although they have identified similar kinds of processes. Studies have demonstrated both vertical and horizontal artifact displacement, the extent of which is somewhat predictable (Gifford-Gonazles 1985, Goerke 1981, Villa 1982, Wilk and Schiffer 1979). Impacts appear to be dependent upon the types of cultural materials, the intensity of trampling or treading, depth of artifacts, and the compactness of the site's substrate. (Gifford-Gonzales 1985:817, Wilk and Schiffer 1979).

Impacts of mechanically crushing brush on the Prescott National Forest (using a Marden Brush Crusher) were investigated by Wood (1979). Mechanical brush treatment is sometimes used for chaparral control or conversion to grassland. Actual sites were used in the tests along with burial of ceramic flower pots to evaluate subsurface impacts. Eighty-six percent (86%) of the surface artifacts were impacted in some way with the most common impact being loss from the surface inventory. Overall, the brush crusher produced four times as much impact to surface materials and structural components as did natural factors at the control site.

Numerous experiments involving impacts of plowing and other modern agricultural practices have been conducted which are relevant to Forest Service vegetation manipulation activities in the Southwest (c.f. Medford 1972). The most recent study, by Odell and Cowan (1987:480), substantiates conclusions reached in a series of previous studies of artifact movement in the plow zone, and documents the enormous effect of tillage on the archaeological record. Plowing often greatly increases the surface size of sites while decreasing artifact density (Odell and Cowan 1987:481, Roper 1976:373); vertical artifact movement varies by artifact size with larger objects more likely to be brought to the surface than smaller ones (Lewarch and O'Brien 1981); and artifact breakage is common (Mallouf 1982:80). While the Forest Service does not undertake plowing per se, we do engage in comparable surface and subsurface soil mixing and disturbing activities.

Use of mechanized equipment in fire suppression activities obviously can impact archaeological materials, and fire itself can destroy sites with combustible materials such as log cabins or roof beams in pueblos. The La Mesa fire near Bandelier National Monument in 1977 (Traylor et al. 1979) and several fires in the Coconino and Pinnacles National forests (Pilles 1984) have enabled studies of equipment impacts, increased site visibility, and artifact alteration because of high fire temperatures.

Prescribed burning is becoming a common management tool for fuels management, wildlife habitat and silvicultural improvements. Several researchers have examined the effects of prescribed burning upon cultural resources (Jones and Euler 1986, Manuel 1980) although these studies have not been particularly successful. Fire management and soil studies indicate that potential impacts to cultural resources depend on several factors: the intensity of heat, duration of heat, the amount of fuels on a site, and the penetration of heat into the soil. It appears that the conditions under which most prescribed fires occur generally would not result in unacceptable impacts to archaeological materials (such as artifact spallage or fracture); however, given the damage observed from natural fires over sites and artifacts (Burgh 1960, Switzer 1974), these impacts need to be quantified more rigorously.

Although not commonly associated with the Forest Service, the presence of lakes and rivers in national forests necessitates some consideration of the effects of flooding and inundation on archaeological sites. A cooperative effort of the US Army Corps of Engeneers, US Bureau of Reclamation, US Soil Conservation Service, and National Park Service (Lenihan et al. 1981) included a wide range of experiments

designed to assess the effects of water on archaeological resources and the best ways to mitigate the negative effects of water impoundment on these materials. These studies provide a good basis upon which to expand inundation experiments and to review methodologies appropriate for related impact studies.

Many other management activites which impact cultural resources have not been investigated. Road construction and maintenance is one which readily comes to mind. In addition, the indirect impacts of Forest Service management have rarely been formally examined.

Human Impacts

Virtually every study mentioned above and most others I reviewed observed that, while the particular impacting agents being examined did affect archaeological sites, site vandalism represents the greatest impact to sites in general. The extent of vandalism in the Southwest has been widely documented (McAllister 1979), and this topic is also being considered in "Protection and Preservation" [work group], however some consideration is necessary here because of the need for experimental research to determine the kinds of actions which may deter people from vandalism (signs, threat of law enforcement, education) (Lyneis et al. 1980).

Accessibility and visibility appear to be the two main factors responsible for human impacts to sites. In the Little Colorado drainage of Arizona, Lightfoot (1978) and Francis (1978) found that almost one third of the variability in some expected artifact classes is the product of removal of materials from sites, and that sites within 1/2 mile of roads and near campgrounds and picnic areas appear to have been subjected to more surface collection than those further away. Other researchers have reached similar conclusions (Schiffer and Gumerman 1977:295).

Site disappearance due to high recreation use has been documented on the Sawtooth National Forest (Gallagher 1984). Also, recreational collecting has resulted in the presence of virtually no portable artifacts on many sites in southeastern New Mexico as documented in the Brantley Reservoir area during archaeological survey for the Bureau of Reclamation (Henderson 1987).

Even child's play has been examined in terms of the creation of features out of previously disturbed artifacts (Hammond and Hammond 1981), and Schiffer (1987:75) cautions that odd associations of artifacts created by "child's play refuse" are often misinterpreted by archaeologists.

Site Survey Impacts

The archaeological survey is the most frequently used research tool in Forest Service cultural resource management and often forms the basis of our knowledge of much of prehistory in the Southwest. If, however, different archaeologists do not consistently recognize, identify and record the same types of archaeological information, then interpretations regarding cultural variation may be a result of the ways in which surveys are conducted rather than the archaeological record itself. "Site Discovery and Definition" is the subject of another work group, however experimental research is needed on this topic also. Plog, Plog, and Wait (1978:391-393) have demonstrated that 90 percent of the apparent variation in site density between 20 survey projects in the Southwest could be explained by the labor invested in the fieldwork. Differences in crew training, spacing and site expectations need to be measured because each has the potential to affect the reliability and interpretations derived from surface archaeological data.

Artifact collection over many years can lead to drastic changes in a site's surface. Inferences drawn from these sites at different times also vary (Ammerman and Feldman 1978, Henderson 1987, Schiffer 1987). In general, artifact variability decreases through time with repeated collection thus making sites appear more homogenous than they actually are, and in the Southwest sites often appear older because the decorated pottery types are collected first (Ravesloot and Spoerl 1981). Systematic review of collections, many of which have been obtained over a more than 50 year time span, is essential from the perspective of both management and archaeological interpretation.

Related to the above, is the issue of developing better strategies for locating sites. Surface visibility varies tremendously depending upon local factors such as vegetation, soil accumulation, alluvial deposition, and weather conditions. Test pits and shovel testing may be appropriate in certain forested areas. The validity of test pit sampling has been examined in some areas (Nance and Ball 1986), and the applicability of shovel tests has been assessed in forested areas throughout the country with varying results.

Agency Impacts

Agency management goals and philosophies and the differences among them may impact cultural resources (Czaplicki 1986). The National Park Service has long held a strong preservation philosophy, and research of its parks and monuments, which is then used in public education programs, has been an important component of the cultural resources management program. The generally restrictive use of Park Service lands may make it easier to control impacts to sites

than multiple-use oriented agencies such as the Bureau of Land Management and Forest Service where site avoidance has been the main strategy. The Bureau of Reclamation carries our inventory and protection activities although it deals mainly with mitigation programs as does the Department of Defense. The extent and manner in which legislation is implemented varies by agency, and these kinds of management impacts must be considered, particularly with increasing cooperation and partnerships among these agencies.

All agencies practice a certain amount of site avoidance in their cultural resources programs, however little investigation has been conducted to determine if measures to avoid impacts to sites are actually effective. Physical impact avoidance techniques include actions such as earth burial, rock coverings and fencing. The University of Mississippi Center for Archaeological Research (Thorne et al. 1987) recently conducted research on site preservation technologies by means of a questionnaire sent to over 400 archaeologists and managers in Federal service. Various impact avoidance techniques were reviewed such as burying sites with sand, stone, gravel or concrete (and the morphological changes which may occur); bank and site stabilization through use of rock berms, retaining walls and revegetation; and various other techniques such as fencing, gabions, and signs. The general conclusion was that site avoidance does not necessarily equal site preservation, and that site preservation is something for which we have only noted the outward appearance of a site rather than the potential impacts of the preservation techniques (1987:67). Preservation in many cases will be more costly than other management options. It is interesting to note that the Reservoir Inundation study reached a similar conclusion in stating that "Both resource managers and archaeologists should also understand that site protection is rarely a less expensive option than field testing and limited excavation" (1981:8).

In sum, there has been very little experimental research on management impacts particularly in relation to the tremendous amount of other cultural resources compliance work completed at the federal, state and local levels. Most of the hypotheses which have been developed for experimentation have not been quantified, therefore the results are not replicable. These research efforts also suffer from the use of poorly defined methods of evaluating impacts; thus, the conclusions are based on inadequate definitions of the kinds and nature of impacts. Impacts may be referred to as minimal, moderate, extreme, insignificant, or not as bad as expected.

There has been little attempt in most cases to incorporate related archaeological studies or relevant environmental research, thus each experiment often stands as an isolated entity rather than being integrated into a broader impact analysis framework. These existing studies should, however be carefully reviewed to glean information on how to more effectively approach impact experiments. Most importantly, we need to go beyond simply identifying impact types and attempt to quantitatively assess them, especially if we are to actually use the results of experimental work to evaluate potential effects to archaeological sites.

RESEARCH NEEDS

It may be useful at this point to consider archaeological data and experimental research needs at three levels (as developed by Lenihan et al. 1981 in the Reservoir Inundation Study). First, there are artifacts and artifact assemblages, the material remains that comprise a site. Impact studies at this level would include experiments regarding artifact displacement, loss, and alteration. Most experimental research has been done at this level. Second, there is the archaeological site or activity locus. The site includes artifacts, features, and the environmental context of past use. Impact studies regarding sites could focus on soil movements which alter spatial and stratigraphic contextual relationships. Few studies have been accommplished with the site as the primary focus, and site survey experiments would be relevant here. Third, there is the regional level including the environmental data base, settlement and resource use patterns, and interaction and exchange networks.

This hierarchical scheme was developed in the course of impact studies for the Reservoir Inundation Study because it makes explicit the proposition that cultural values consist not only of discrete entities such as artifacts and sites, but also of the relationships among these entitites. The loss of archaeological data at any level of the hierarchy affects the quality of information obtainable from the other levels. This is particularly important for Forest Service management because we are not merely concerned with the movement of a few or many artifacts from one place to another, but rather knowledge of the whole range of relationships is essential to understanding the past and to proper management. We can consider the relationships (spatial, contextual) of artifacts and features that comprise a site, the relationship among sites comprising a settlement system, and the relationships between a settlement system and its environmental and cultural context.

Range allotment management plans can serve as an example here where all levels of information and impact are relevant. Such management plans may call for placement of new tanks and pipelines, the opening of access roads, pasture fencing, vegetation manipulation to create additional grazing areas, and grass seeding. At what distance from a site should a new tank be placed to avoid unacceptable levels of cattle trampling on the site area?; will fence construction

neccesitate formation of new cow trails which may cross sites and lead to increased compaction, artifact movement, or erosion?; to what extent will new access roads increase the potential for site vandalism and what mechanisms may help discourage such actions?; will seeding of a site distort spatial relationships of artifacts at a later date?; and, what will be the effect of these management activities on the overall archaeological record of an allotment area?

As Wildesen says (1982:75), we need to know how much, how bad, how long, and how rapid. With this information we can decide which impacts are acceptable and which may result in a significant loss of archaeological information (the "threshold of concern" as she terms it (1982:75).

As a result of management impacts research, we should be able to define the range of potential impacts from certain kinds of activities and predict the regularities of these impacts on artifacts, sites and areas. This information can then be evaluated to determine acceptable limits of impacts for various activites and sites based upon the type of archaeological resource, its significance, type of impact, and physical composition of a site area. Archaeologists should be able to say to managers: based upon experimental research an archaeological site will not be impacted if prescribed burning is conducted at temperatures of less than XXX degrees with a sparse understory; at another site the heavy fuel loading must be reduced to avoid high fire temperatures and potential impacts to artifacts. Or, impacts to sites will not be significant if over-snow logging is conducted under conditions of XX amount of snow on the ground with temperatures below XX degrees and done during a XX week period in early morning hours. Without reliable impact information we will continue to simply avoid sites which seldom may be the optimal management strategy.

At this point, we have a general idea of what we do and do not know regarding the potential impacts of various cultural processes. Therefore, the following general research recommendations are made.

1) We need experimental research regarding the nature of specific impacts on archaeological materials and development of a program of integrated impact research. Real as well as synthetic sites should be used, and experiments should include actual ground disturbing projects as well as simulated ones. Studies under controlled conditions can be supplemented with actual projects (e.g. timber sales,) however replicability must be ensured to produce results which can be applied to a broad range of factors not merely one timber sale in one area. Factors which can be controlled include kind and number of artifacts used, size of artifacts, location, and type and frequency of impact (cf. Odell and Cowan 1987:457).

The Forest Service site allocation scheme (Green and Plog 1983) allows for the experimental use of certain sites. Allocation involves the assignment of sites to various categories based on value, including research, interpretation, preservation, removal from management, and experimental use. On the Coronado National Forest we have a number of sites appropriate for experimental use because of a unique land exchange situation.

Experiments can be done on a function specific basis such as timber harvest methods, although there should also be an emphasis on more generalized studies appropriate to a number of functions. As an example, compaction studies can be applied on a number of forests because compaction may be caused by animals, heavy equipment, people, and natural deposition. Other examples include experiments on the impacts of mechanical equipment on soil mixing, and investigation of various effects of trampling and treading.

To be successful, impact research must be conducted in the context of an integrated research program. Individual experiments on a site, project or forest specific basis, as most previous ones have been, will not provide us with the kinds of objective and replicable data necessary to apply results on a regional scale.

2) We need to incorporate data obtained by environmental scientists regarding hydrology, soils, vegetation, and geomorphology into research on cultural processes and impacts.

Much research has been conducted by environmental scientists regarding erosion, compaction, soil and vegetation disturbance and sedimentation associated with ground disturbing activities such as timber harvesting, grazing and recreation. Archaeologists can use these data and apply similar methodologies to archaeological impact studies. As an example, soil and vegetation research can be used to evaluate potential impacts of prescribed fires. Such results would have widespread applicability to Forest Service management.

3) We need field studies on the effectiveness of various techniques intended to prevent vandalism, along with behavioral research on vandals. This topic is also considered in "Protection and Preservation".

4) We need methodological research regarding the archaeological record as reflected by survey standards and site observation and recording. This becomes a particularly important management concern if sites present are not located during surveys, or if too much time/money/effort is placed in areas of low site density or surveying in inappropriate conditions with crews with inadequate training. We now have about 15 years of survey reports and data to use as a basis for such study.

5) We need to to ensure that a long-term comprehensive management impacts program is implemented with follow-up work conducted, and the publication of results.

In conclusion, impacts to the archaeological record should be described and evaluated. We base much of our management on what we see on the ground surface, and we need to know the extent to which this information is reliable. We know sites are not pristine, but we have to be able to more effectively judge the extent to which formation processes have affected them and will affect them because of specific Forest Service management. We need to identify acceptable levels of impacts that are compatible with management activites and still allow for the preservation of archaeological information.

The first step is to formulate and conduct a systematic program of research to understand the nature of impacts associated with Forest Service management activities, and then to determine how most effectively to minimize these impacts to the archaeological record.

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Research Agenda for Management Impacts on Cultural Resources[1]

Stephen Fosberg[2], Joseph Gallagher[3], Thomas Lincoln[4],

Patricia Spoerl[5], and Kenneth Wilson[6]

INTRODUCTION

This research agenda is organized as an addendum to the paper entitled "Management Impacts on Cultural Resources, An Assessment of Forest Service Research Needs" by Patricia M. Spoerl (this volume). The agenda expands upon research recommendations made in that paper and provides information regarding the goals and objectives, knowledge and technology, and research issues needed to address the problems of understanding the nature of management impacts to cultural resources.

The purpose of this research agenda is to provide a framework for instituting a research program to provide archeologists and managers with the information needed to anticipate and systematically manage impacts caused by management activities and natural processes on cultural resources. Information on impacts will ensure a proactive approach to cultural resources management in that specific kinds of impacts may be predicted and appropriate measures taken to minimize these impacts. In addition, acceptable impacts resulting from various management activities can be defined which will not adversely affect significant values of particular cultural resources.

[1]Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2]Stephen Fosberg is the State Archeologist, Bureau of Land Management, New Mexico State Office, Santa Fe, New Mexico.

[3]Joseph Gallagher is Zone Archeologist, Southern Idaho National Forests, Boise, Idaho.

[4]Thomas Lincoln is Project Archeologist, Bureau of Reclamation, Arizona Projects Office, Phoenix, Arizona.

[5]Patricia Spoerl is Forest Archeologist, Coronado National Forest, Tucson, Arizona.

[6]Kenneth Wilson is Cultural Resources Specialist, Six Rivers National Forest, Eureka, California.

The result of impacts research is envisioned as a series of technical reports which provide specific information on anticipated impacts to cultural resources from specific management activities.

The "state of the art" with regard to management impact research is minimal (Spoerl, this volume). Experimental studies on management impacts have generally been on a site- or project-specific basis, and have not included the kinds of objective and replicable data necessary to apply results on a regional scale. There has been little attempt to incorporate related archeological studies or relevant environmental research. so each experiment usually stands as an isolated entity rather than being integrated into a broader research framework. The studies which have been completed should, however be carefully reviewed and evaluated to form the baseline from which to proceed with an integrated research program.

Five research recommendations were made in "Management Impacts on Cultural Resources: an Assessment of Forest Service Research Needs" that outline directions management impacts research

should pursue. One of these, treating vandalism and site-protection study needs, is not included here because the issue is given detailed consideration in another work group (Christensen et al., this volume). Site protection is, however, a significant component of managing impacts to cultural resources, and can easily be integrated into a broader Impacts Research agenda. The other four recommendations will be expanded upon in what follows.

We need experimental research regarding the nature of specific impacts on archeological materials, and development of a program of integrated impact research. We need to incorporate data obtained by environmental scientists regarding hydrology, soils, vegetation, and geomorphology into research on cultural processes. We need methodological research regarding the archeological record as approached by survey standards and site recording techniques. And, we need to ensure that a long-term, comprehensive management impacts program is implemented with follow-up work conducted. The nature of much of the experimentation necessitates a long-term commitment to examine the impacts of various processes on the archeological record although specific short-term studies also form an important component of the program.

BASELINE DATA NEEDS

Prior to development of a viable research program, baseline data must be collected and analyzed. Such data are needed to make more informed cultural resource management decisions. Development of these baseline data involves both survey and inventory work and research, and should be conducted as a joint effort of the Forest Service management and research branches. Immediate data needs are: (1) completion of an overview/analysis of experimental research; (2) identification of "Comprehensive Study Units" and identification of cultural resources appropriate for impacts research; and (3) resubmission of the 1982 National Science Foundation experimental research proposal.

A comprehensive and detailed overview and critique of all experimental studies carried out to date must be undertaken. As Wildesen (1982: 53) points out, "Unfortunately, much of the 'literature' on impact studies exists as papers at meetings or in journals of limited circulation." Nearly all of these studies have been sponsored on a sporadic basis by Federal agencies and have not been published in the formal literature. Consequently, researchers will have to obtain copies of these unpublished reports from individual field offices, and will need to analyze which approaches are worth pursuing and which should be abandoned. The conclusions of this analysis should suggest to management which experimental designs to incorporate into the formal Forest Service research program on management impacts.

Another objective of the overview/analysis is to assess what technology is needed to implement the impacts research program. Existing laboratory and field methodologies and technological needs should be reviewed in terms of the impacting agents themselves, as well as in terms of the science of archeology. Development and scoping plans for designing equipment or technology necessary for measuring changes in site conditions or artifactual content should be included.

Identification of "Comprehensive Study Units" is an important component of the research program effort, and could be coordinated by the management branch. The units would consist of relatively large geographic areas containing cultural resources which are scheduled for some type of management activity. Management activities in these units would be monitored on a long-term basis, as would be the use of the units for experimental studies. Each forest could be polled on the availability of such areas. From the list generated, the areas can be evaluated in regard to overall management and research objectives to identify which geographic areas will constitute the Comprehensive Study Units. Defining these units should be based on the following factors: cultural resource density, distribution and quality; extent of previous impacts; resource accessibility; degree of proposed future development; resource applicability and availability to experimental research; and compatibility with Forest plans.

Knowledge of general site types within an area would be necessary to develop specific kinds of impact experiments. The identification of Comprehensive Study Units amenable to experimental work would also entail the identification of specific cultural resource sites outside these areas which might be appropriate for impacts research.

Reviewing, updating, and resubmitting Upham and Green's (1982) experimental research proposal to the National Science Foundation (NSF) could lead to a variety of experimental data. Also, there is a potential for the development of a partnership among the Forest Service, an academic institution, and the National Science Foundation to carry out some research without relying solely upon Forest Service research funds. While the existing proposal would not require complete reworking, revisions should emphasize the priorities established in this paper.

RESEARCH ISSUES

Under the rubric of Management Impacts, the potential for research is so broad that it is necessary to reduce and classify the possible topics based upon kinds of impacts and importance to Forest Service management. The Management Impacts Group conceptualizes the Research Issues in three broad classes: (1) programmatic issues; (2) functional issues; and (3) generic issues.

This categorization reflects the authors' perceptions of how to address research questions and how different lines of research should be carried out (table 1).

Programmatic issues concentrate on those effects which are further removed in time and space than immediate project impacts. Areas of programmatic concern include secondary impacts, protection/avoidance treatments, and long-term impacts-monitoring programs within Comprehensive Study Units. Functional issues are those dealing with traditional Forest Service program areas such as timber, range, fire, and recreation. Generic issues are topical categories that focus on a class of discrete impacts such as soil mixing, trampling, compaction, and thermal alterations, which are impacts caused by a variety of functional activities. Functional impacts tend to be program-specific, while programmatic and generic issues crosscut Forest Service functional activities.

Table 1.--High priority research issues in impacts research.

Programmatic Issues:
- Secondary Impacts to Cultural Resources
- Comprehensive Study Units - Inventory and Monitoring
- Avoidance/Protection Measures

Functional Issues:
- Impacts of Fire on Cultural Resources
- Impacts of Timber Management on Cultural Resources
- Impacts of Range Management on Cultural Resources

Generic Issues:
- Impacts of Soil Mixing using Mechanical Equipment
- Impacts of Human and Animal Trampling and Treading
- Impacts of Erosion on Cultural Resources

RECOMMENDATIONS OF THE MANAGEMENT IMPACTS GROUP

Secondary Impacts to Cultural Resources

The Management Impacts group recommends that the Programmatic topic of Secondary Impacts receive priority consideration. This recommendation is made because: (1) we expect that managers will continue to use site avoidance as a management strategy, leaving sites at risk within project boundaries from indirect impacts; and (2) sites are at risk from activities such as hiking, boating, hunting, and touring which have no direct impacts themselves, but which have varied and poorly understood indirect effects. The latter is becoming a critical concern because of the current high recreation use of National Forests and the potential increase in recreational activities with the Recreation Initiative.

The goals of proposed research on secondary impacts are: (1) determine the scope and scale of secondary impacts that occur across all functional areas (although the focus will be on recreation-related impacts initially); (2) determine which cultural resources are at greatest risk from secondary impacts; and (3) develop techniques which managers can use to reduce secondary impacts to a level where their effects do not alter National Register characteristics.

Analyses of secondary impacts should stress an integrated study approach encompassing many of the thematic issues presented by other work groups at the Symposium. Study areas could include: (1) interpretative/educational factors and their effectiveness in preventing secondary effects; (2) site protection and preservation technologies and how human behavioral data can enhance these efforts; and (3) site discovery/definition concerns, especially where secondary impacts could alter or entirely remove subtle cultural resources from the landscape.

Research results that would produce information meaningful to managers would require three to five years to acquire, and could require a second five-year period to observe and assess accurately long-term, persistent secondary effects.

Comprehensive Study Units

The Southwestern Region needs to obtain data on the variability and extent of impacts on a wide range of archeological sites within confined geographical areas. This information will assist in making informed program management decisions for future development. Comprehensive Study Units, in which such investigations would be conducted, should be between 2000 and 6000 acres in size, and should contain a variety of archeological resource types representative of the area. These areas should have no or little past development, so that site analyses, interpretations, and significance determinations can be undertaken with consistent and comparable data. Development programs and management activities should proceed under current cultural resources guidelines, so that potential impacts to cultural resources can be measured under standard Forest Service practices. Impacts to sites, site avoidance, site protection, and mitigation measures should be applied in the traditional manner, so that cumulative impacts can be assessed. This program can, and should, be applied to other aspects of cultural resources research, so that a wide array of topics can be addressed (e.g., research issues, site definition, vandalism). A minimum of three Comprehensive Study Units should be established in the Region to ensure good variability in areas and activities, as well to as establish some comparability among impact studies.

Archeological sites in the Study Units will be inventoried and recorded to the best current survey standards. Inventory would be an initial aspect of study which could involve experimental research in various survey and site-recording techniques. Mandated compliance obligations will be met by making significance determinations and, where applicable, National Register nominations. Because of the continuing nature of many Forest Service activities, a time period of at least fifteen years is recommended to conduct these studies. Sites will be monitored on a recurring and scheduled basis to assess changes, both natural and cultural, that might have occurred since the previous monitoring.

Experimental studies should be developed within the framework of the Comprehensive Study Units and should include creating "sites" for specific problem analyses. At the conclusion of the study an impact assessment will be prepared which will describe and evaluate impacts to cultural resources caused by routine Forest Service activities. This should be a significant contribution to effective management of cultural resources.

Protection/Preservation Efforts

A variety of actions may be undertaken to avoid impacts to sites including burying sites with various materials, bank- and site-stabilization, and revegetation. Research on this topic would focus on potential impacts to internal site structure which may occur from avoidance and protection strategies (e.g., whether the weight of sand or stone affects the distribution of subsurface artifacts; whether these materials introduce new matter which may alter the chemical composition of organic materials; and the erosion potential of the covering materials).

Test sites would be placed in a variety of environmental situations with a variety of coverings. Experiments would use both manufactured sites, and actual sites that have been partially excavated. Acquisition of "before" information on the nature of the site, and on soils and other environmental data, would be necessary. Experiments would be long-term (e.g. five to fifteen years), with impacts measured periodically.

FUNCTIONAL ISSUES

Fire Management

Fire and fire management activities have the potential to impact cultural resources such as chipped stone, ceramics, shell, basketry, bone, carbon samples, and floral and faunal materials. A critical research question associated with fire relates to the impacts of heat on cultural materials, and on natural materials in a cultural context. Does heat change the physical and chemical characteristics of artifactual materials? For example, what effect do varying levels of heat have on obsidian sourcing and hydration readings? These questions regarding potential impacts on archeological information are very important in relation to such fire management activities such as prescribed burning, back firing in fire suppression, and maintaining fuel loads on cultural resource properties.

Fire impacts research could be completed in a relatively short amount of time, about one to two years.

Range Management

Studies done to date on the effects of range management on cultural resources have been by Goerke (1981), Lightfoot (1978), Logdon (1976), and Roney (1977). However, these studies have generally failed to rigorously control the independent variables which condition the severity of grazing upon cultural resources.

Under this proposed experiment, manufactured, artificial sites would be produced along the lines suggested by Upham and Green (1982). Holding the cultural resource component constant, grazing conditions to be varied would include: degree of soil compaction, moisture conditions, size and type of soil constituents, animal types, numbers of animals, the number of passes over a site, the size and weight of the animals, and the context of the site.

A fast track (accelerated experiment) and a slow track would be followed to measure the results. The fast track would concentrate the numbers of animals in a small area to simulate effects over a longer period of time. The slow track would measure changes utilizing the density of animals and conditions expected in the real world.

Observations to be made would include examining edge damage, and comparing fractures and bulbs of percussion. Vertical and horizontal displacement or disappearance would be calculated by periodic remapping and comparison to initial piece plotted maps. Weight measurements and binocular microscopes would be used to measure changes. The research would specifically seek to answer the question whether impacts can be distinguished from intentional human modifications.

Timber Management

Research on timber management involves studying the overall impacts to cultural resources by timber management activities. These activities include falling, yarding, site preparation, and plantation management. Secondary effects that should be studied are impacts to cultural materials that are adjacent to or surrounded by timber harvest units. We have been creating

cultural resource islands within timber stands by our standard practice of flagging and avoiding sites. It is suspected that impacts from windthrow might be one result of creating these islands.

This comprehensive study would occur over a five-year period to insure that a wide array of logging systems and silvicultural prescriptions are tested within several different ecological/environmental settings. There is a potential for cooperation between logging companies and the Forest Service in conducting these studies.

GENERIC ISSUES

Similar kinds of impacts may occur in different types of Forest Service activities. These can be investigated as topical research questions which crosscut a series of functional areas. The functional nature of Forest Service management (e.g., range, fire) may not always be the most effective, economical, or even desirable method of conducting research. Generic issues can most effectively be joined with natural resource research or within Comprehensive Study Units, and can thereby be accomplished either as individual experiments or as components of related environmental studies.

Soil Mixing Studies (Mechanical Equipment)

Disturbance of archeological sediments can have tremendous effects on the distribution of archeological materials and the structure of sites. Forestry literature contains information on the kinds of soil disturbance that occur as a result of timber harvest. This literature can be drawn upon in designing and implementing research on the impacts of soil-disturbing activities, both from timber harvesting and from other Forest Service practices such as road construction and vegetation manipulation through mechanical treatments.

Trampling/Treading Studies

Trampling and treading occur through the presence of animals (e.g. cattle, horses, sheep) and humans with similar kinds of impacts. Concentrated areas of compaction and disturbance are created with impacts that can be relatively well-defined and which occur in relatively patterned ways. Identifying these patterns would be the focus of experimentation, and these studies would build upon existing ones conducted in this country and abroad. The overview/analysis would be instrumental in identifying the most productive lines of research.

Erosional Impacts

Forestry and range literature contain a considerable amount of information dealing with both direct and indirect effects of erosion. Because erosion generally occurs some time after a specific activity has been completed or at a location distant from the actual activity, its impact on cultural resources is not always recognized or considered. Research on this topic would focus on incorporating studies of artifact movement and displacement into work being conducted by other environmental researchers.

BUDGET CONSIDERATIONS FOR HIGH PRIORITY RESEARCH ISSUES

Budget estimates are obviously quite tentative at this point because impacts research can be conducted in a variety of ways which may be integrated with other aspects of cultural resources research. The extent to which it may be desirable to coordinate such research will substantially affect the cost of conducting experimental studies.

General cost estimates for the high priority issues identified in this impacts research agenda are summarized in table 2.

SUMMARY

The research agenda outlined above proposes three major lines of management impacts research, and the topics within them that are considered to

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Table 2.--Impacts research costs.

Programmatic Issues:
- Secondary Impacts - ca. $200,000 per yr., 5+ years.
- Comprehensive Study Units Inv./Monitoring - ca. $200,000 per year, 15 years.
- Preservation/Avoidance Measures - ca. $100,000 per year, 2 years.

Functional Issues:
- Fire Management Impacts - ca. $75,000 per year, 2 years.
- Timber Management Impacts - ca. $100,000 per year, 5 years.
- Range Management Impacts - ca. $75,000 per year, 5 years.

Generic Issues:[1]
- Impacts of Soil Mixing
- Impacts of Trampling/Treading
- Erosional Impacts

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[1]Because of the general and multi-functional nature of the generic studies, they can be staged in a variety of ways with budgets ranging from minimal to large depending upon the complexity and length of time of experimentation.

have the highest priority for research. These issues focus on the major impacts which affect cultural resources. Research on them can provide comprehensive results to ensure that cultural resources receive appropriate management treatment.

As discussed at the Cultural Resources Research Symposium, management impacts research can be joined with a number of aspects of the research outlined in other work groups. Most closely related is that of the Protection/Preservation work group. The recommendations made by that group and those made by the Management Impacts group could quite effectively be consolidated into a generalized Cultural Resources Impacts Research framework which would include investigation of impacts to cultural resources from the public, from natural forces, and from management activities. The need for research dealing with cultural resources has been amply demonstrated. The next step is to determine how this research can best be structured and organized.

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United States Forest Service: Programmatic Issues Concerning Native Americans[1]

E. Charles Adams[2]

Abstract.--The USFS has interacted at the forest level with Native American groups for many years. Utilizing a questionnaire sent to forest archaeologists in the Southwest Region, this paper discusses the perceptions the USFS has toward Native Americans and suggests ways to alter patterns of past behavior, to rectify false impressions, and recommends programmatic changes to improve relations.

The United States Forest Service (USFS) and American Indian Tribes are both land managing entities, albiet the forest service more in a stewardship role whereas reservations are set aside for the use of specific groups. Often these lands are contiguous, sharing lengthy boundaries. In the western U.S. most Native American groups have had at least part of their original land base set aside on their reservation. This has played a significant role in their ability to maintain a cultural identity. It has also allowed Native Americans to retain a strong identity with their land base, their greatest resource, and to maintain ties with lands off the respective reservations, as well as on. Many of these traditional lands are now managed by the USFS. This has required the development of relations between the tribes and the forest service to effectively deal with potentially conflicting uses based in part in cultures having different value systems.

This paper explores the relationship of the USFS to Native Americans through the eyes of forest archaeologists, those individuals most frequently assigned the task of managing the forest´s cultural resources by the forest supervisor. To assess the cultural resource manager´s view of his or her forest´s relations to Native American groups in touch with the forest, a questionnaire was sent to archaeologists from 11 forests in the Southwest Region. Nine responses were received and these form the bases to the characterizations accorded the forest service in this paper. Although the responses on the questionnaire may or may not accurately reflect forest service policy, the responses do reflect the perspective of those most directly involved with the day-to-day contact the forest has with Native American groups.

LEGAL ISSUES AND ACCESS

The USFS legal obligations to Native American groups are defined by a number of acts and USFS rules and regulations promulgated under these acts. The act most prominent with respect to Native American rights is the American Indian Religious Freedom Act of 1978 (AIRFA) and associated USFS rules and regulations. Secondary legislation includes ARPA (Archaeological Resources Protection Act of 1979), NEPA (National Environmental Policy Act of 1969), HPA (Historic Preservation Act of 1966), Rangeland Renewable Resources Planning Act, and associated rules and regulations, such as 36 CFR 800 and 36 CFR 219. These acts, rules, and regulations require the USFS to involve Native American groups in the planning process for the individual forests and requires the forest service to allow Native Americans access to forest service lands in pursuit of objects or resources essential to the practice of their religion, even into areas normally off-limits to the general public.

Beyond specific legislative mandates involving Indian tribes, Native Americans are allowed the same access to forest service lands as any other American. Although access is not specifically limited, as with other individuals or groups, a special use permit is required to collect any materials. For some forests there is no fee for this permit. Interestingly, although most forest service land would be, or would have been, part of some, or several, Native American groups´ aboriginal lands, few are actively pursuing claims and seem satisfied with the access they are afforded to these lands. It is also possible that Native American groups generally do not acknowledge the authority of the forest service to control their removal of items from

[1] Paper presented at the Forest Service Cultural Resources Research Symposium, May 2-6, 1988, Grand Canyon, Arizona.

[2] Associate Curator, Arizona State Museum, University of Arizona, Tucson.

forest service land and thus do not bother to obtain permits. It also may be that they fear the permit process and thus do not use forest service land due to the permit requirements. Neither instance is satisfactory to the forest service and makes management of their resources more difficult.

USFS - NATIVE AMERICAN CONTACTS AND RELATIONS

Results from the questionnaire suggest that cultural resource managers for the USFS believe their relations with Indian Tribes are satisfactory; however, close scrutiny of the questionnaires detects what may be an underlying cause for this feeling and that is the small amount of interaction that takes place between the manager/archaeologist and his/her Native American "constituents". By constituents is meant those Indian tribes that a forest either must contact to review research designs or planning documents as required under ARPA or those tribes that claim aboriginal use of some part of the forest. Generally, these two groups are the same, but occasionally a tribe is not legally required to be given the opportunity to review documents, but nevertheless may claim aboriginal use.

Although relations are characterized as satisfactory, there is a lot of frustration felt on the part of the cultural resource managers. This is due in part to tribes' general nonresponses to requests for comments or review of legislatively-mandated documents. With the exception of the request for use permits, which are initiated by the tribe or its members, all other contacts are initiated by the USFS. These contacts are infrequent, formal, and almost always legislatively mandated. Contacts are usually by letter, although forest archaeologists that view their programs as being most successful or satisfactory in terms of their relations with Native Americans also frequently have phone and personal contacts. Other than permits and mandated tribal reviews of research designs, contacts with Indian Tribes involve either minor disputes over boundaries and some resources, and questions of access or protection of properties on forest service land deemed significant by a particular tribal group. Such properties almost always involve sacred or religious areas still known to the tribe which may or may not be threatened. Although Indians are generally viewed as nonresponsive, because tribal governments seldom respond to requests made by letter, apparently no systematic attempts have been made to determine why. Poor relations, as with any issue of some dissatisfaction, are usually attributed to inadequate money, time, personnel, and low priority within the system, or a combination of some or all.

STAFF RECOMMENDATIONS

Several interesting recommendations for enhancing relations with Native Americans were voiced by the respondents. Two thought that changes should be made within the tribes because the USFS was not getting responses to their requests for comments. Although many tribal governments are inefficient, if not unresponsive to requests, it would seem that a more reasonable solution to the problem on nonresponse might be to evaluate USFS procedures rather than expect every tribe to change or improve theirs. In point of fact is might be a problem in the way the forest service requests comments, rather than what they request.

Other recommendations are more constructive. One suggestion is to include Native Americans more in forest service interpretation and planning activities. A second suggestion is to remove policy-making for Native Americans from the local forest to the regional office. Finally, it is suggested that relations with Native Americans be made less formal. Each of these recommendations belies a general sense of frustration on the part of the forest archaeologist in dealing with Native Americans and the seeking of a solution to improving these relations. The heart of the issue seems to be that more and better contact with local tribes is needed and should lead to more communication and, ultimately, to improved relations.

In general the problems, as detailed or hinted in the questionnaire, can be summarized as follows:

(1) The forests are generally doing a good job of fulfilling their legislatively-mandated contacts with Native Americans, but

- (a) They are not seeking to do a better job, at least not systematically.
- (b) They do not understand the Native American perspective on issues
- (c) They do not have the resources to do a better job (perhaps this is an allocation problem)

Some forests, however, are doing more than others with respect to Native Americans and their results have been interesting. The improved results have been accomplished through more personal contacts with tribes or individuals and attempts to involve Native Americans in the planning process. These are the forests that are the most satisfied by their relations to Native Americans. The conclusion that must be drawn is that more effort can lead to better relations and better relations can lead to better results in Native American involvement in forest service management of cultural resources and other issues.

SOLUTIONS

Given the above discourse, what methods can be identified that might yield the best results given the recognized resource allocation problems within the forest service? First, the allocation of resources must be considered. Allocation is in part a matter of setting priorities. If Native Americans are to be more fully involved in

planning and interpretation, then effecting this involvement must be given a higher priority. The forest supervisor together with the forest archaeologist must establish where Native American input is not only mandated, but also desired. Once internal priorities are established, then external priorities must be established. What are the Native American concerns and what solutions are there to these concerns? Of course the forests have sought Native American input for the last several years. The problem is how to get the tribes to express these concerns. The lack of input by tribes does not mean they have none. It means that the forests have not found the means to encourage the tribes to express these concerns.

My experience with tribes is that they inherently distrust institutions (especially of the federal government), but respond quite positively to the individual approach. By this it is meant that within each forest it would be quite useful to establish a "liaison" to handle all Native American "issues", acting, more-or-less, as a clearinghouse. Just as important to establishing this liaison is giving this person authority. The liaison should have direct access to the forest supervisor and not be forever tangled in red tape when it comes to needing decisions or action. If the liaison is powerless, the tribes will soon realize that just another barrior has been erected and the results will be more damaging than healing. If an individual acting in this liaison role is seen as effective and can be easily accessed by local tribes, input from tribes should increase markedly.

The Native American liaison cannot be a passive agent waiting to respond to Native American needs or contacts. This individual must take an active role in making contacts and ferreting out concerns. Each tribal entity should be contacted and visited. The structure of each tribe is unique and should be learned and understood. Who are the key people to contact over religious issues, wood issues, water issues, permits? Who is the chairman and how is he or she accessed? Who handles cultural resources? Is there an environmental or cultural section? It may be useful to produce a brochure explaining the function of the liaison office that identifies who the officer is either within the brochure of with a business card. The brochure should be simple and to the point giving examples of what services the liaison provides to the tribe.

When the tribe is so large in size as to have contacts with more than one forest, such as the Navajo Tribe, liaison may best be handled from the regional office. Otherwise, the Navajos may get three or four versions of forest service policy.

Initial contacts should yield tangible results. Demonstrating that the "system" works will give the tribes confidence in the liaison and encourage them to seek that position again. If the person acting as liaison is to change, it is important that the replacement be personally introduced by the outgoing liaison to smooth the transfer.

Before investing forest resources in a liaison office and setting off on an unchartered course, it would be well to contact other forests and even other regions to find out what programs they have tried, what has failed and been successful, and why. Learning from others experiences should make the particular course chosen by the forest a more successful one.

By going directly to the tribes the USFS has in effect opened the lines of communication. (It should be kept in mind that a translator should be available or used by the forest service representative.) The forest service should be ready to listen and to visit the tribes, often the tribal council, in person. It is recommended that this contact be made by the liaison. This person, by virtue of their link directly to the forest supervisor, should be informed and involved in all matters before the forest involving Native Americans. Armed with this information the forest service liaison can clearly and simply outline the forest's priorities to the tribe, how they can affect the tribe, how the tribe can have input into the planning and development processes, and so on. In return the liaison should request the tribe's priorities (or have them make-up such a list) involving resources on or use of USFS land. By determining the priorities, needs, and problems of both sides, solutions can be discovered.

Native Americans have access to USFS lands equal to all Americans; however, Native Americans have special needs and concerns of access and use that can require special considerations or unique solutions to potential problems. By opening lines of communication the USFS will become aware of potential problems much sooner and have many more options avilable as solutions. Native American groups are not only users and consumers of forest service lands, they can potentially enhance the resources under USFS care. The enhancement process can be achieved through Native American identification of resources significant to their culture whether they be natural or cultural. Identification and interpretation of these resources can enhance everyone's understanding and appreciation of the resource and allow the USFS to adopt innovative and meaningful ways of protecting the resource. This can include Native American participation in the interpretation and protection process.

CONCLUSIONS

The USFS must take a more active role in its relationships with Native American groups. To improve relations it is essential to open the lines of communication. Before communication can be successful it is essential for the forest service to know in what areas Native American input is mandated and in what areas Native American input could enhance forest service planning and development. Information about the

latter can probably be improved by directly contacting tribes and obtaining information about specific needs and concerns. To facilitate opening and maintaining communication channels it is recommended that a "clearinghouse" of Native American involvment in forest service planning and management be developed within each forest and at the regional level. This clearinghouse will be the province of a Native American liaison officer who will have direct access to the forest supervisor, have access to all forest service actions or plans that may affect or interest Native American groups, and develop "personal" contacts with each tribe that has legal or other interests with the forest.

The purpose of the liaison is to open lines of communication between both parties, with both groups benefitting. Native Americans should benefit by having input into the planning, interpretation, and perhaps even management of resources under USFS control. The USFS should benefit by servicing a new sector of the local community, Native American people, and by being able to better manage its cultural resources through obtaining input from tribal groups.

This paper is presented as an idea paper intended to provoke comment and discussion. Suggestions to improve Native American - USFS relations are not panaceas or perhaps are not even practical within the USFS management system. It is incumbant, however, on the forest service to take the initiative in opening and expanding lines of communication with Native American groups. To act in a passive manner expecting tribal groups to work within the system established by the forest service is not only naive, it is poor management. Native Americans have much to offer forests in enhancing the identification, protection, and interpretation of cultural resources under USFS management. There is no time like the present to begin tapping this resource or to reevaluate programs already in place.

Acknowledgements.—I would like to extend my appreciation to those forest archaeologists from the Southwest Region who took the time to complete and comment on the four page questionnaire I sent them on Native American-USFS contacts and relations. Although the responses on these questionnaires have led to many of the conclusions drawn in this paper, the conclusions are my own and should not be construed as representing the views of the forest service or of forest service archaeologists. The comments did provide the main spark to the ideas presented in this paper and I willingly share recognition for such.

Forest Service and Native American Relationships: Considerations for Research[1]

Sonia Tamez[2]

INTRODUCTION

One of the announced purposes of this conference is to "identify and prioritize research needed to strengthen relationships with, and promote understanding and appreciation of, contemporary cultural groups that have links to the past."[3] This paper addresses the context in which such research can be formulated and conducted.

All sociocultural research is influenced by developments in laws, regulations, and land-use issues affecting the participants in the research effort. A lack of recognition and understanding of the sociopolitical context can lead to ineffective problem identification, hypothesis development, data gathering, analysis, and conclusions. Therefore, I want to discuss key events and forces that have shaped Forest Service/Native American relationships in the past, and identify major developments that will affect future relationships. I will also make recommendations regarding research topics, methodologies, and approaches to conducting research that are responsive to the sociopolitical context I will outline here. Throughout this paper, I will bring in examples from California to illustrate certain points.

PAST INFLUENCES ON FOREST SERVICE/NATIVE AMERICAN RELATIONSHIPS

The following discussion of agency policy is based on research conducted by Tamez and Laidlaw in an examination of Native American policy developed by the Forest Service (FS) and the Bureau of Land Management (BLM) in California.[4]

The management emphasis for the Forest Service is on the use of land and natural resources. Within California, Federally-administered lands comprise approximately 48% of the land base and contain most of the undeveloped lands in the state. The Forest Service administers 20 million acres; BLM administers 17 million acres.

The Forest Service has been identified with forestry and timber production, but is currently emphasizing developed recreation and fish and wildlife habitat improvement programs. The Forest Service permits and regulates many other uses and activities such as hydroelectric development and mineral exploration.

The consideration of Native American social and cultural values in Forest Service decision-making grew out of concerns regarding the effects of Forest uses on cultural resources. As the Nation's environmental conciousness and social awareness changed over the past two decades, the scope of Federal law was extended to protect not only natural resources, but also cultural resources. Agencies such as the Forest Service responded to legal requirements to assess the effects of federal actions upon cultural sites by developing Cultural Resource Management (CRM) programs.

Although the Forest Service has managed cultural resources for over fifteen years, its CRM program did not have, until recently, affirmative preservation and interpretation objectives. The Forest Service's CRM program as originally instituted was reactive - responding to projects and activities that might adversely affect cultural resources.

The nature of the Forest Service's CRM programs is critical to understanding the Forest Service's relationships with Native Americans because it is through the CRM program that Native American values were first considered in land management planning and program and project development. Although the National Environmental Policy Act (NEPA) of 1969 and the National Historic Preservation Act (NHPA) of 1966 referred to the cultural aspects of our heritage and intangible values, federal agencies interpreted the implementing regulations as applying to material culture - specifically archeological sites. Native American values usually were only identified when considering the significance of archeological sites, and this was only one element of the potential significance of

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[1] Paper presented at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2] Sonia Tamez is Forest Planning Coordinator for the USDA Forest Service, Pacific Southwest Region, San Francisco, CA.

[3] Letter dated August 21, 1987 from David F. Jolly, USDA Forest Service, Southwestern Regional Office, Albuquerque, New Mexico, to conference participants and other interested parties (file designation 2360).

[4] Tamez, Sonia and Robert Laidlaw. 1988. The Multiple-Use Mission and Cultural Conservation. Paper presented at the Annual Meeting of the Society for California Archaeology, Redding, California.

archeological sites. Consequently, Native American concerns were isolated from other social group values and diluted when viewed in the context of archeological site significance. The Forest Service relationship with Native Americans was largely defined in terms of identifying and mitigating the effects of agency projects and activities on archeological sites.

A few years ago, Forest Service planning started responding to Native American concerns in an affirmative way. Agency projects and programs started to be defined, at least in part, in terms of meeting Native American community needs for protection of both natural and cultural resources. Cooperative agreements were made regarding exchange of information and sometimes of land. Special projects were initiated to promote resources important to Native American communities.

The change in Forest Service/Native American interaction actually had its origins in agency response to environmental legislation enacted during the 1960s, such as NEPA. Agencies were mandated to plan comprehensively and to involve the public more in decision-making. Agencies were also required to incorporate interdisciplinary perspectives in land management and project planning.

Traditional agency values and historical management emphases were challenged, and agencies like the Forest Service became more concerned with sociocultural values in an effort to anticipate and moderate the conflicts that accompanied planning.

Also during the sixties, there was a growing awareness of civil rights as a National issue. Civil Rights legislation mandated that federal agencies take the lead in ensuring that agencies actively support the civil rights of the Nation's citizenry, and consider the effects of agency programs and projects on the civil rights of agency clients and neighbors.

In the seventies, other legislation reinforced mainstream civil rights law and influenced agency relationships. The American Indian Religious Freedom Act (AIRFA) was passed in 1978. This Act established a national policy to protect and preserve the right of American Indians to exercise freely their traditional religions. This joint resolution also required agencies to evaluate their own policies and procedures as they affect the religious rights and cultural identity of Native Americans. This resolution reinforced the First Amendment rights to religious freedom.

To understand the impact of AIRFA, we need to go back to the First Amendment. It states:

> Congress shall make no law respecting the establishment of religion, or prohibiting the free exercise thereof, or abridging the freedom of speech or of the press; or the right of the people peaceably to assemble and to petition the Government for a redress of grievances.

The first clause is referred to as the Establishment Clause" and is the basis for the principle of separation of church and state in this country. The second clause is known as the "Free Exercise Clause" and is the basis for much of the litigation based on the First Amendment and AIRFA.

Benchmark First Amendment cases include the following:

Sherbert v. Verner (374 U.S. 389, 407 [1963])--The court ruled that the government must not indirectly burden religious practices.

Wisconsin v. Yoder (406 U.S. 205, 214 [1972])--The court ruled that a litigant making a free exercise claim must first prove that the state has burdened important religious interests. Once impairment is established, the state must demonstrate, in order to prevail, that there is an overriding public interest.

Both cases established that the government must do more than identify a public interest; the state must show that to accommodate the religious practice in question would specifically harm the public interest. The state must also demonstrate that no less-burdensome means is available to implement the policy.

AIRFA was intended to respond to charges that Federal Agencies were inadvertently impairing Native American religious freedom. In an effort to address these problems, AIRFA required Federal agencies to review their policies and procedures. If any of an agency's policies infringed on Indian religious freedom, it was to take appropriate action. Various recommendations for further legislative action were viewed during the Carter administration at the time, but subsequent law and rule-making were not forthcoming.

Despite AIRFA, a number of Supreme Court cases specifically arguing restrictions on Native American First Amendment rights followed:

Sequoyah v. TVA (Cherokee) 449 U.S. 953 (1980)

Badoni v. Higginson (Navajo) 452 U.S. 954 (1981)

Fools Crow v. Gullet (Cheyenne and Lakota) 785 D.S.D. (1982)

Inupiat Community v. United States (Inupiat) 182 D. Alaska (1982)

Wilson v. Block (Navajo and Hopi) 735 D.C. Cir (1983)

All of these cases resulted in the defeat of the Native American plaintiffs. These losses in the courts shifted efforts to statutory solutions. On March 31, 1988, Senator Cranston of California introduced a Bill, S. 2250, which would amend the

American Indian Religious Freedom Act (AIRFA) of 1979 in order to "ensure that Federal lands are managed in a manner that does not impair the exercise of traditional American religion." Section 3(a), the major provision of the bill, states that:

> Except in cases involving compelling governmental interests of the highest order, Federal lands that have been historically indispensable to a traditional American Indian religion shall not be managed in a manner that would seriously impair or interfere with the exercise or practice of such traditional American Indian religion.

Senator Cranston was joined by Senators Inouye and DeConcini. The bill went before the Senate Select Committee on Indian affairs, now chaired by Senator Inouye, on May 19, 1988.

S. 2250 is designed to reinforce AIRFA and, by extension, the First Amendment. Some agencies had expressed the opinion that in the absence of explicit statutory law directing them to do so, they could not manage lands and areas to protect Native American values without violating the Establishment Clause which requires a separation of Church and State. The bill is a response, in part, to that position and gives agencies legislative support for deciding to protect traditional sacred areas. The bill also goes beyond the review of policy into land management activities themselves.

S. 2250 has been given impetus by a recent Supreme Court ruling. On April 19, 1988, the Supreme Court ruled on Richard E. Lyng, Secretary of Agriculture, et al., Petitioners v. Northwest Indian Cemetery Protection Association et al., a case commonly known as the G-O road case. The court decided that the First Amendment's Free Exercise Clause does not forbid the Government from permitting timber harvesting in, or constructing a road through, portions of the Six Rivers and the Klamath National Forests that had been traditionally used for religious purposes by the Yurok, Karok, and Tolowa peoples.

Although the court found that there was nothing in the First Amendment that requires the federal government to preserve sacred sites, the court emphasized that the government needs to be sensitive to and consider Native American values. In the majority opinion report, Justice Sandra Day O'Connor wrote that:

> The Government's rights to the use of its own land, for example, need not and should not discourage it from accommodating religious practices like those engaged in by the Indian respondents.
>
> It is worth emphasizing, therefore, that the Government has taken various steps in this very case to minimize the impact that construction of the G-O Road will have on the Indian's religious activities.

Previous courts had established a three part test specifically for Native American religious use. This test was most eloquently articulated by Pamela Ann Rymer, U.S. District Judge (see Coastal Band of the Chumash Nation, et al. v. Ventura County, [1986]). Briefly the test questions are:

1. Is the religious practice central and indispensable?

2. Is there a governmental burden on the free exerciser?

3. Are there overriding public interests?

The court also ruled that the judiciary had no role in deciding centrality, but left it open to other institutions to assume the responsibility.

Regulatory institutions have been assuming some of that responsibility. The new implementing regulations of the NHPA (September 1986) emphasize public involvement and concern with sociocultural values by emphasizing the elicitation of community concerns, particularly among Native American tribes and groups. The criteria used to evaluate sites for the National Register of Historic Places have also been reinterpreted to include nominations of areas where the dominant values are sociocultural values.

Another development that might affect research directions is in the realm of natural resource management case law. The courts are going further in assessing cumulative and aggregate effects on natural resources, and starting to cross over into sociocultural effects. In a recent examination of ten major court opinions, Tamez identified four specific analogies that could be used to assess better the effects of agency activities on sociocultural groups.[5]

Research is needed to assist the Forest Service in responding to current trends in the courts, in the legislature, and in regulatory agencies. Ethnographic research is needed to identify traditional use areas and ways to minimize impacts. Research regarding contemporary use and values could assist in assessing the impacts of various project and land management options.

METHODS AND APPROACHES

The previous section dealt with potential topics for research. In this section, I want to focus on how research on Forest Service/Native American relationships should be conducted.

There is a danger of utilizing archeological paradigms for this research, arising from the

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[5]Tamez, Sonia. 1988. Cumulative Effects, Socio-Cultural Values and Land Management. MS in possession of the author.

close tie between the CRM program and archeology. We have to understand the epistemological underpinnings of both the archeological inventory and ethnographic study, and recognize the inappropriateness of using archeological paradigms to assess sociocultural values. As Laidlaw has noted:

> The value of important cultural materials to the archaeologist resides not only in the physical resources themselves but rather in the potential that these hold for answering significant research questions; these research questions and their theoretical context constitute the technical "world view" of the professional archaeologist. The value, then, of Cultural Resources for the archaeologist is largely assigned by the archaeological community. These assignments are dynamic and subject to change as the prevailing theories, methodologies, and analytical constructs of the discipline change.
>
> As is the case with all cultural groups, members of Native American traditional cultures have a world view that assigns the relative value and significances of features of the natural and cultural environment. Just as the world view of the archaeologist embodies basic epistemological tenets; so too does the Native American world view embody basic epistemology (Laidlaw 1987: 2).

As we recognize the legitimacy of paradigms outside of archeological ones for assessing sociocultural values, I anticipate that we will be adding ethnographers and social or cultural anthropologists to CRM and Planning staffs. We should also look at creating new partner ships outside the Forest Service - specifically, with the Native American communities who have traditional ties to the lands now managed by the Forest Service. I want to illustrate the possibilities with two examples from California.

The tie between California Native American communities and public lands has always been great. However, the changing land-use and ownership patterns in the state, and the changing priorities and needs of established reservations and rancherias, have contributed to a broader interest in resources and services provided by the Forest Service, as well as by other Federal land managers.[6]

Many communities are initiating a revitalization of traditional ceremonies that must take place in certain kinds of areas and that require certain natural resources. These practices are rooted in the past and, although suppressed for decades, have continued in some form. With the lifting of government sanctions on native religion, renewed traditional expression of cultural values is not only desired but deemed critical, in many cases, to the survival of the community.

For many groups, the sites and resources necessary for cultural maintenance are not available or accessible except on Forest Service, BLM, or National Park Service lands.[7] Private lands have been developed, resulting in damage or destruction of sacred areas. In many cases, unfortunately, private land owners have not felt a responsibility to make ceremonial status or critical resources that may be located on their lands available to Native Americans.

Reliance on sites and resources on public lands is the only option for many groups in their attempts to continue to exercise and express their religious values and beliefs. Public resources and lands are essential to cultural survival.

At the same time that Native Americans' reliance on public lands is increasing, other kinds of competing uses are also increasing. Recreation, energy, and other major capital investments and developments, and long-term allocations such as Wilderness designations, are increasingly "shrinking" the public land base. The need for planning prior to development and allocation, in order to reduce the potential for conflict between Native American use and other competing uses, has become more acute. The need for interagency coordination in order to facilitate Native American use of public lands has also become apparent. Native American community needs for certain kinds of resources perhaps could be met by a number of agencies working together. Although original, traditional areas are preferred, when they are altered so much that they aren't usable, substitutes can be sought. Areas that may have been secondary are becoming primary if they are now the only accessible areas.

In November 1986, the BLM, NPS, and the Forest Service met to identify the specific program elements that could be addressed by joining agency efforts. A standing interagency committee consisting of Roger Kelly, representing NPS; Robert Laidlaw, representing BLM; and myself, Sonia Tamez, representing the Forest Service, was established in February, 1987. Larry Meyers, Executive Secretary for the Native American Heritage Commission, represents the Commission and meets with the group.

This group is working on the following five issues and opportunities:

1. The need for consistent consultation policies.

2. The crisis regarding vandalism of Native American sites on public lands.

3. The integration of information regarding sensitive sites into land management planning.

4. The treatment, preservation, and protection of human burials and associated goods.

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[6] _op. cit._ (in note 4).

[7] _op. cit._ (in note 4).

5. The fostering of a better understanding among all federal agency personnel regarding the values, concerns, and rights of Native Americans who use public lands.

This institutional partnership is undertaking major policy changes in the agencies that manage over 40 million acres of lands traditionally used by Native Americans in California.

Another California example of a partnership, one that is more research-focused, is that of Helen McCarthy of Theodoratus and Associates and several members of the Sierra Miwok community. Archeologists had been working under the assumption that the depth of bedrock mortars in the region was due to the length of time they had been used in the processing of acorns. Ethnographic work with some of the Sierra Miwok revealed that the depth is correlated with intended function. Some bedrock mortars were specifically created shallow in order to process certain types of seeds while others were originally created deep in order to process other types of seeds, or utilized at various stages of seed processing. This information regarding material culture could not have been obtained without utilizing a paradigm different from the archeological paradigm, and is the result of a new partnership with the Native American community.

The importance of partnerships with the Native American community has been furthered by a landmark policy which will also have implications for research regarding Native American relationships. The long-awaited NPS Native American policy was issued last year. This policy concerns Native American use of National Parks for traditional and religious purposes. Key provisions include:

- extensive and intensive consultation with Native American groups of all age groups, men and women, traditional and political leaders, and religious practioners; and

- consideration of traditional values in decision-making regarding land uses, interpretation, and treatment of archeological sites.

The NPS policy has set the pace for other agencies. The Forest Service will be expected to follow suit. Implications for research include:

- the need for Native Americans to be working in partnership with the Forest Service to identify traditional values and to conduct other related research; and

- the need to utilize approaches that are different from those currently employed for understanding material culture. Specifically, contemporary Native Americans should be consulted regarding artifacts, features, and archeological sites.

SUMMARY AND CONCLUSIONS

We can expect competing uses of public lands to increase as the general public becomes more aware of public lands and as private lands become more developed. We will also see an increasingly active Native American community. Community interest in resource management decision-making will continue to grow.

All these developments point toward a consideration of cultural research for land management and project planning. The federal agency response is moving from a position where it has been focused on only the protection of material culture. Federal agencies such as the Forest Service are now concerned with how they affect cultural identity and the maintenance of cultural diversity.

For the past two decades, federal agencies have made a substantial commitment to the protection of archeological sites. CRM programs were developed to stimulate protection of material culture, and focused on the identification and treatment of archeological sites. Research is critically needed to shift the Forest Service emphasis from material culture to include sociocultural values, in order to respond to current trends in the courts and in the legislature, as well as in the communities the Forest Service serves.

The consideration of sociocultural values calls for a perspective different from that appropriate for material culture resources. The discussions above illustrate that this research requires a multi-disciplinary approach and a new partnership with Native American communities. The growing body of case law demands a legal perspective and suggests some topics for study. The civil rights associated with access to and use of culturally important natural and cultural resources must also be addressed.

Anthropological models and methodologies are essential in order to identify both resources and values. Consultation with Native Americans and the collection of basic ethnographic data are critical. And finally, but perhaps more importantly, we need to recognize the importance of Native Americans as partners in research regarding their relationship with the Forest Service.

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Modeling Solutions to Indian Needs Concerning Cultural and Natural Resources on Forest Service and Other Public Lands[1]

E. Charles Adams[2], Elizabeth Brandt[3], Edmund Ladd[4], Terrance Leonard[5], Peter J. Pilles, Jr.[6], and Sonia Tamez[7]

The goal of the Southwestern Region of the Forest Service, in its relationship with the many tribes of the Southwestern United States, should be to provide a coordinated inter-agency and tribal partnership to promote mutual understanding of, and participation in, the management of National Forests and other public lands.

As a multiple-use agency the Forest Service, besides considering the effects of its activities on "special interest groups" such as Indian Tribes, is also charged to provide opportunities for such groups to accommodate their needs and desires to use Forest resources, consistent with laws and regulations and the needs of other Forest users. Various Forests have provided for Indian needs, and have actively sought ways to improve relationships with Indian peoples. For example, hiring of Indians for fire-fighting crews is a long-standing tradition in the Forest Service; assistance has been offered and given to help tribes develop para-archeology programs and to conduct investigations and prosecutions of pothunting cases; timber is provided to groups such as the Hopi to construct and rebuild pueblos and kivas; and several Forests have initiated land exchanges to acquire private property on which shrines were known to be located so that they could be better protected as public land.

Despite these positive activities, Indian needs and concerns are not understood and are not being met by the Forest Service as well as the agency understands and meets the needs of other user groups. This lack of understanding is one factor that has resulted in lawsuits and conflicts related to such things as ski developments on sacred mountains, mining activities, and access to special areas.

The Southwestern Region of the Forest Service is unique in several aspects of its relationship with Indians. First, few Forest Service regions have the number of tribal groups with such cultural stability and continuity as are found in the Southwest. Specifically, 39 Federally-recognized tribes have access to the 11 National Forests within the Southwestern Region. Today, these tribes are represented by a number of tribal organizations, as listed below.

Tribal Groups	National Forests of Tribal Interest
Arizona Tribes and Forests	
Hopi	Coconino, Kaibab, Apache-Sitgreaves, Prescott
Navajo	Coconino, Kaibab, Apache-Sitgreaves, Cibola, Santa Fe
Tonto Apache	Coconino, Prescott, Tonto
White Mountain Apache	Apache-Sitgreaves
Chiricahua Apache	Coronado
San Carlos Apache	Apache-Sitgreaves, Coronado
Havasupai	Kaibab, Coconino
Walapai	Kaibab, Coconino
Paiute	Kaibab, Coconino
Northwestern Yavapai	Prescott, Kaibab, Coconino
Southeastern Yavapai	Tonto
Pima	Tonto
Tohono O'otam (Papago)	Coronado
Yaqui	Coronado

[1]Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2]E. Charles Adams is Associate Curator at the Arizona State Museum, University of Arizona, Tucson, AZ.

[3]Elizabeth Brandt is Associate Professor of Anthropology, Arizona State University, Tempe, AZ.

[4]Edmund Ladd is Curator of Ethnology at the Museum of New Mexico, Santa Fe, NM.

[5]Terrance Leonard is Community Development Specialist with the Salt River Pima-Maricopa Indian Community, Scottsdale, AZ.

[6]Peter J. Pilles is the Forest Archeologist of the Coconino National Forest, Flagstaff, AZ.

[7]Sonia Tamez is Forest Planning Coordinator with the USDA Forest Service, Pacific Southwest Region, San Francisco, CA.

New Mexico Tribes and Forests

Zuni	Cibola, Apache-Sitgreaves, Coconino, Coronado
Laguna	Cibola
Acoma	Cibola
San Ildefonso	Santa Fe, Cibola
Santa Clara	Santa Fe, Cibola
San Juan	Santa Fe, Carson
Tesuque	Santa Fe
Pojoaque	Cibola, Santa Fe
Nambe	Cibola, Santa Fe
Zia	Cibola
Santo Domingo	Santa Fe
San Felipe	Santa Fe
Santa Ana	Cibola
Sandia	Carson, Santa Fe, Cibola, Lincoln
Picuris	Carson, Santa Fe
Taos	Carson, Santa Fe
Jemez	Santa Fe, Cibola
Isleta	Carson, Santa Fe, Cibola, Lincoln
Cochiti	Santa Fe
Mescalero Apache	Gila, Lincoln
Jicarilla Apache	Santa Fe
Navajo	Cibola, Santa Fe

Oklahoma Tribes and Forests

Cheyenne	Cibola

Second, many tribes continue to use all or part of one or more Forests as part of their cultural sustaining areas. Third, many tribes, in some cases confirmed by archeological research, have historic and prehistoric remains on lands managed by the U.S. Forest Service.

LEGAL MANDATES

The U.S. Forest Service is mandated to consult with Indians in the conduct of its management activities by a number of laws and regulations. The most prominent of these are:

- The American Indian Religious Freedom Act

- The National Environmental Policy Act

- The National Forest Management Act

- Forest and Rangeland Renewable Resources Protection Act and its implementing regulations, 36 CFR 219

- The Archaeological Resources Protection Act

- Protection of Historic Properties (36 CFR 800)

The Forest Service is required to consider the effects of its land management activities on Indian groups. However, there are no accepted or consistent process, standards, or guidelines for eliciting and incorporating Native American concerns in land management or project plans. Consultation and involvement of Indians, when solicited at all, is seldom brought in at the earliest possible planning stage, but often late in the process, when it is difficult to modify project plans to accommodate Indian needs and concerns. Because current approaches tend to be reactive, with few changes made to accommodate Indian concerns, negative attitudes, mistrust, and a lack of understanding characterize much of the relationship between Indians and the Forest Service.

Existing laws and regulations focus upon protection and evaluation of archeological resources, historic structures, and other physical remains that are over 50 years old. Consequently, other cultural resources of significance to Native Americans are often excluded from cultural resource consideration. In addition, non-material concerns, newly derived religious needs, and continuing needs for access to Forest lands and Forest products are overlooked. The requirement for documentation of an age greater than 50 years devised for historic sites overlooks gaps in the ethnographic record and the bias of the time when an ethnography was compiled.

Indian cultural areas, regions, and sites are in the greatest danger from adverse impacts to any cultural resources because their inherent cultural values, and even the existence of such areas, are largely unknown outside the Indian community. In addition, unlike some archeological sites, adverse effects to many areas of American Indian concern cannot be mitigated by documentation, excavation, or even avoidance. Indian concerns are not uniform, even within the same tribal group. There are concerns with archeological materials, land management practices, and resources on Forest lands.

Many Native Americans also desire interpretation that reflects individual tribal views on archeological sites and the cultural landscapes of which the Southwestern Forests are a part.

The concept and definition of cultural resource management must be broadened to include these cultural concerns and non-material remains if it is to provide for improved relations with Indian users of the Forests. Development of an improved process for involving Indians in the Forest Service planning process will increase management efficiency, reduce costs in project redesign, and reduce the chances of expensive litigation resulting from projects that affect Indian concerns. It would provide an opportunity to preserve and protect from project impacts the cultural sites and resources that might be overlooked by traditional survey techniques. Such a broadened perspective of cultural resource management could also provide for Indian interpretations of cultural ties with sites and land uses, enhancing our understanding of the Southwestern Forests as part of a cultural landscape.

PROBLEMS IN FOREST SERVICE-INDIAN RELATIONS

The broad concerns expressed above can be narrowed to specific problem-areas, which are as follows.

1. Indians do not know who to contact to express their interests in, and concerns for, Forest management activities. Efforts to solicit information and involvement of Indians in the project-planning process are inconsistent among Forests. Indian consultation in some Forests is done by the Forest Archeologist, and in others by Land Management Planners or the Civil Rights Staff. Conversely, Forests do not know how or who to contact to solicit information from tribal groups. For example, in an effort to cover all bases, some Forests send blanket "consultation" letters to groups and organizations that nominally represent many tribes. Information received from these groups may or may not reflect the actual concerns of the affected tribes, or specific groups within the tribes that may be most directly affected by the proposed project.

2. Past destruction of habitat has removed plant and animal species needed by Indians.

3. There is a lack of knowledge and understanding by Federal personnel of trust responsibilities, Indian treaty rights, and uses of Forest lands and resources by Indians. Such lack of understanding has recently been singled out by the Chief of the U.S. Forest Service's Civil Rights Task Force. It has led to such things as:

a. District personnel harassing Indians when they were collecting plants and minerals; and

b. Forests requiring Indians to obtain permits in order to collect natural materials.

Many Indian communities resent the control of any collecting of forest materials and products by the Forest Service, excepting endangered species, since many tribes have a strong conservation and stewardship ethic.

4. There are no consistent policies or procedures to safeguard the security of information concerning sacred places or traditional uses when such information has been provided to the Forest Service. Nor are there any policy statements protecting Forest Service Cultural Resource Management Specialists from divulging information they have received under promises to keep such information secret when the specialists are brought into litigation involving Indian concerns and Forest Service practices.

5. Tribes are seldom notified of Forest Service project plans and Forest Service personnel seldom know when their projects may affect Indian values and activities on Forest lands.

6. Privacy is needed at certain times by Indians when they are collecting materials or performing religious activities. Privacy is also needed when cultural resource specialists interview Indians or when Native people examine special areas within the Forests. Forest activities often take place in the same areas at the same time as Native activities. Better scheduling is needed to ensure privacy and avoid conflicts at such times.

7. Although all Forests have some ethnographic overviews, particularly the Cibola and Santa Fe National Forests, most are very incomplete and none is comprehensive. The quality of the information is normally drawn from old published sources and, due to the dynamic nature of Indian cultures, is outdated and inadequate for management or planning.

8. Reburial of human remains and associated artifacts is an emotion-charged issue to archeologists and Indians alike. Some tribes and Indian organizations assert that no excavations should be done. Others wish to have such studies to learn more about their past and to reaffirm their cultural identity. The impetus for such demands has largely come from Indian-rights groups and tribes outside the Southwest. Such issues must be addressed by the Forest Service, yet no research has been done with individual tribes to determine their attitudes on these matters.

RECOMMENDATIONS TO IMPROVE FOREST SERVICE-INDIAN RELATIONS

While many of the problems cited above will require long-term commitment to resolve, some immediate improvements can be made, as recommended in the following paragraphs.

1. The Forest Service should deal directly with individual tribes, and with those groups most directly affected by proposed activities. There are many groups and associations that represent or claim to represent Indian peoples, and it is often considered expedient to consult with them rather than try to identify specific tribal concerns. However, Forests should not consult with such groups to the exclusion of the individual tribes unless those tribes wish the Forests to do so.

2. As part of Forest land management planning, range allotment analysis, biological surveys, and timber stand compartment examinations, opportunities for habitat improvement for plants and animals needed by Indians should be identified.

3. Sensitivity training sessions should be conducted in each Forest Supervisor and District Ranger office to educate Forest Service personnel on the needs and legal rights of Indians to collect materials from Forest lands, and on the legal limits to such collecting. The job descriptions of Staff and Line Officers should be amended to include responsibilities for ensuring that Indian consultations are done for projects and activities in their area of authority.

4. Forests should consider abolishing individual permit requirements for Indians who wish to collect natural materials for personal, non-profit uses. Alternatively, consideration could also be given to issuing blocks of permits to tribal governments and allowing them to issue the permits to individual tribal members.

5. Until a national policy is produced, the Regional Forester should issue a supplement to the Forest Service Manual stating that it is Regional policy that information collected by the Forest Service from Native Americans about sacred places, sensitive collecting or use areas, and associated activities is respected and will be held in confidence. It is restricted for necessary uses by the Forest Service and the tribal source and will not be disseminated to other tribes, Indian groups, or other entities unless otherwise approved by tribal officials or the Native individuals concerned. Forest personnel are required to adhere to professional ethical codes when acquiring such information, and must promise to maintain its security.

6. Each Forest should appoint a liaison to coordinate Forest and tribal consultation, and should encourage the tribes it deals with to designate a liaison of their own (see below).

7. There is a need continually to consult with Indian tribes on a project-by-project basis. Interested persons should be consulted on Forest Service activities that will affect Indian resources or activities. Consultation should begin as early as possible and continue until the project has been completed, or dropped. Direct consultation is necessary even though other ethnographic information may be available, since existing information may not be complete or current, and project impacts must be considered in context. This is a dynamic partnership, with needs changing on both sides, and will lead to a reevaluation of the effects of specific impacts on resources. A process to develop a consultation process is proposed later in this document.

8. When particularly sensitive places have been identified, or certain activities requiring privacy are known to occur in certain areas of a Forest, consideration should be given to designating them as cultural resources management areas. Appropriate prescriptions should be developed for those areas to ensure proper protection of the material and non-material cultural values within them.

9. Forests must have base-line information on Indian uses of each Forest, and the concerns and attitudes of Indians toward activities allowed on Forest lands. The following section suggests the content of ethnographic overviews that can provide such information. The remaining problem areas described above cannot be adequately addressed until specific information about the attitudes of pertinent tribes to these problems is known. It is one function of the overviews to acquire this information.

DRAFT GUIDELINES FOR THE PREPARATION OF ETHNOGRAPHIC ACCOUNTS OF NATIVE AMERICAN USES, VALUES, AND VIEWS ON FOREST SERVICE ACTIVITIES

To address these and other Indian issues and concerns adequately, the following initial guidelines are recommended. They provide for the kind of ethnographic information and identification of cultural concerns that are relevant for planning and management. They should not be taken as exhaustive, and are subject to revision by individual Forests and tribes to reflect their own unique perspectives and situations. These Guidelines should be used to produce comprehensive ethnographic overviews for each Forest, and it is the consensus of the authors that the production of such overviews is the prime research need of the Southwestern Region of the Forest Service. Because such overviews are needed by all Federal agencies in the Southwest, it is suggested that the most efficient and cost-effective way of obtaining this information is to conduct and fund it as an interagency endeavor. Conducting such studies as a coordinated, interagency approach would also minimize impacts on individual tribes who would only have to provide such information once, rather than several different times to different agencies soliciting the same information.

As part of collecting this ethnographic information, a data base should be constructed of tribal uses and concerns. Obtaining such historical-use information will give Forests information that will be useful for resolving conflicting demands for access, use, or land claims, as well as to avoid or prepare for potential future lawsuits over such issues. This information should be coordinated and collected by the tribal groups themselves within these guidelines. The research need not and should not be restricted to these areas alone. This ethnographic and ethnological data base should be considered to be baseline documentation which provides initial information for use in Forest Service planning efforts. Recognizing that culture is dynamic, and that values change, this ethnographic data base should be frequently updated as part of Forest Service Land Management Planning reviews, or when a tribe requests that such an update be made.

We recommend the following guidelines:

1. Identify the relationship of each tribe or Indian group to the Forest(s).

2. Identify objectionable actions and practices in Forest Service land management.

3. Identify acceptable actions and practices in Forest Service land management.

4. Identify ways in which Native peoples use Forest Service land and resources:

a. Identify items collected, including species identification, if allowable by tribe, for:

1. plant materials, including timbers for construction needs;

2. birds and other animals; and

3. minerals.

b. Where allowable by tribe, identify different sites and areas used for the collection of these resources.

c. Where allowable by tribe, identify how factors such as access, availability, and condition of the resource to be collected influence the choice of these areas.

d. Identify seasonality and cyclicity of collection and use.

5. Identify the uniqueness and/or significance of the resource. For example, if the only source for a particular material is in a Forest, it would be of unique and irreplaceable value for a community.

6. Identify any need for privacy when using an area.

7. Identify any need for confidentiality of the information collected during the ethnographic study.

8. Identify any need for habitat maintenance and improvement or restoration of key species utilized by Indian people.

9. Identify sites or areas and their locations, if possible, that have significance because they are sacred or because of associations with historic (including oral-historic) or supernatural persons, events, or activities.

10. Determine if tribes can provide a "prioritized" list of sacred or other special places that are important for management to protect. Identification of significant areas should be a first-order priority for ethnographic studies. Such areas should be identified for management as soon as possible, and information about the locations of such areas should be kept confidential by the Forest Service.

11. Consult with each tribe to determine what kinds of information and issues they would and would not like to see presented in Forest Service interpretive projects on prehistory and modern Indian groups.

12. Determine what the tribes see as pertinent research issues and how these might relate to archeological and management-related Forest Service research issues.

13. Determine tribal attitudes and understanding of archeology. Specifically, identify the attitudes of tribal members toward site excavation, excavation and treatment of human remains, and reburial of human remains and artifacts.

TRIBAL PRODUCTION OF ETHNOGRAPHIES

For tribes that wish to participate in providing cultural information to the Forest Service and other Federal agencies, we recommend that individual tribes should be given the opportunity to conduct their own ethnographic research, since this is the best way to obtain current concerns and viewpoints. Tribes are in the best position both to identify and to access those people who have knowledge on sites, activities, and areas, and to represent their concerns about Forest Service land management activities.

These studies would not be total ethnographies, but would focus on the types of information suggested in the Draft Guidelines (above), and on other information relevant to particular tribal and cultural group concerns as they relate to National Forest or other participating agencies' lands.

Some tribes may have personnel who can conduct these studies, or they may wish to contract for the study. Forest Service Cultural Resources Specialists, or perhaps a Regional Ethnologist (see below), would have the responsibility of assisting tribes in designing, conducting, training for, or contracting for such studies, if desired. Forest Service funds should be available to tribes to conduct this research. Funds could also be available from other cooperating Federal agencies, such as the Bureau of Land Management, the National Park Service, and the State Historic Preservation Office. The latter office has certain funds to assist in the identification of significant cultural properties that may be appropriate as well. Normal research grants, such as those of the National Endowment for the Humanities, could also be pursued.

A PROPOSAL FOR COORDINATING INDIAN CONCERNS IN FOREST SERVICE PLANS

At the present time, the Southwestern Region of the U.S. Forest Service has a checkered and inconsistent program for obtaining information and comments from Indian groups relative to proposed Forest projects. Only four Forests (Cibola, Coconino, Kaibab, and Santa Fe) have developed programs to work with tribal groups. Only these four have regular communication with tribal groups regarding Forest Service projects and activities. Other Forests engage in dialogue with Indian groups when particularly sensitive or controversial projects arise.

There are several critical reasons for the lack of adequate information on Indian concerns and cultural sites. Major reasons are over-worked staff, lack of clarity on who has responsibility for the collection and curation of such data, and lack of effective continuing consultation with Indian tribes, organizations, and individuals. Mutual trust, understanding, and involvement of Native Americans can only occur when formal

procedures have been established that provide a mechanism for the effective exchange of information.

In order to address the problem at the management level, we propose a two-pronged program for developing working partnerships between tribes and the Forest Service: designation of Forest Service and tribal liaisons, and creating the position of Ethnologist in the Regional Office.

Each Forest Supervisor and Tribal Council, or Federally-recognized tribal authority, would designate responsibility for Forest Service-tribal relationships to one individual. Formal responsibility for consultation remains with the Forest Supervisor and the Federally-recognized tribal authority, although actual communication and action in this area is done through the delegated liaison. The Tribal Council or Federally-recognized tribal authority would determine whether or not the tribe chooses to participate in such a coordination program with the Forest Service. Should the tribe choose to participate, the tribal liaison would seek out concerns and interests of the various groups within the tribe and communicate these to the Forest Service liaison. When there is a change in tribal administration, or appointment of a new Forest Supervisor, each liaison will be approved for continuation or a new liaison appointed.

A major function of the liaisons is to provide an interface to promote effective communication between the Forest and the tribe. By having sufficient training and sensitivity, each can better explain the needs, desires, or problems of their constituencies. For example, the Forest liaison may be better able to explain the need and impacts of a timber sale to a Indian group than could the forester. Similarly, tribal concerns expressed to the Forest liaison by the tribal liaison could be better explained to Forest Service personnel by the Forest liaison. The Forest liaison could also communicate Indian rights to use Forest lands and resources, as well as treaty obligations, to field-level Forest Service personnel.

The use of liaisons has worked successfully and provides incentives for both the Forest Service and Indian groups to begin and maintain effective communication. It also fits into the organizational structure of the Forest Service and most tribal governmental structures, and meets the formal requirements of various laws, regulations, policies, and protocol procedures between agency and tribal officials.

Although simply appointing someone does not necessarily ensure that adequate consultation and communication will follow, there is a better chance for this than if no one has formal responsibility. Administrative assurance that the Forest Service and tribal liaisons provide useful communication and consultation is accomplished by requiring that liaison duties be part of the formal job description of each individual. A further assurance of success from the Forest Service side is that effectiveness of the program would be examined as part of the General Management Review process that all Forests undergo periodically by the Regional Office.

For the Forest Service, it would be ideal to have a professional ethnologist assume such functions on a full-time basis on each Forest. However, viewed pragmatically, this may not be a viable solution at the present time. Individual Forests need to decide where within their organization coordination with Indian tribes is best handled. Unique situations in individual Forests may result in coordination being best handled by different functional units. However, there are pros and cons to placing this responsibility in different units. It should ideally be placed in a unit that is familiar with all project activities proposed and on-going on a Forest at any given time. This is generally the Forest Supervisor, Deputy Forest Supervisor, Budget and Finance section, Land Management Planning section, and the Cultural Resources Management section, although other divisions, such as Public Information, could also be considered.

If conducted by the Supervisor or Deputy Forest Supervisor, contacts would be maintained at the level of administrative equals, that is, at the level of ultimate authority for each Forest and tribe. However, these individuals do not have the time to conduct such dialogue effectively. Although Budget and Finance sections are aware of projects funded for a particular year, they seldom know a project's current status and are usually not aware of future project planning. If the liaison is placed within the Land Management Planning section, Indians would be given the same status as other user groups that are routinely queried by planners as part of the project planning process. However, because of its involvement in ensuring that all on-going projects have cultural resources clearance, and in planning adequate funds and time for future projects, most Forests will likely find that this responsibility is best placed in the Cultural Resources Management section. There are several reasons why the liaison may be best located in the Cultural Resources Management section.

First, recent changes in the Southwestern Region's procedures for coordination of projects and consultation with the State Historic Preservation Office now require the Cultural Resources Management section to assemble a list of all projects planned each year on each Forest. The CRM section verifies the cultural resources clearance status of each project and submits the list to the SHPO for consultation regarding inventory levels and existence of known significant cultural properties, as required by 36 CFR 800.4. This list can also be sent to interested tribes both to inform them of proposed project plans and to solicit information regarding culturally sensitive areas or other concerns that can be addressed at the time the cultural resource survey of the project areas are performed. As

this master project list is revised in the CRM section, revisions can also be sent to interested tribes to keep them apprised of the status of each project.

Second, most people in Forest CRM sections have had some education, training, or experience in cultural anthropology and ethnology. This should give them some skills in effective communication with non-Anglo cultures, skills that are lacking in most other Forest Service personnel. Although the Civil Rights section has similar sensitivity, it generally does not have the knowledge of project status that the Cultural Resources Management section has.

Third, by locating such responsibilities in the CRM section, one of the current problems identified above - that "cultural resources" must be expanded to include more than prehistoric and historic archeological sites - is addressed.

Adams' study (this volume) identifies several problems hindering effective Forest Service-Indian communication. Specifically, tribes tend to distrust Federal agencies, and are often reluctant or unwilling to respond in writing to consultation requests. Once communications are personalized, distrust of the faceless bureaucracy will fade and higher response rates will be achieved, since each group knows who to contact when a potential problem or a need for consultation arises. When the Forest liaison suspects potential conflicts or concerns, informal consultation can be made with the tribal liaison to verify such concerns and arrange for meetings with appropriate tribal people. Discussions with them may result in compromises or solutions before, or perhaps without a need for, formal consultation correspondence between the Forest Supervisor and the duly elected tribal official. Conversely, when a tribe has a need for Forest resources or services, the tribal liaison can discuss such needs with the Forest liaison, who can make appropriate arrangements within the Forest Service organization to respond to such requests.

Consultations are best kept at a personal level, as suggested above, because tribes do not understand the Forest Service organizational structure or its distinction from other agencies. In a similar vein, few agencies understand the traditional or political organization of the various tribes. By developing personal contacts, these problems can be solved and considerable time saved.

REGIONAL OFFICE PROFESSIONAL ETHNOLOGIST

Although designation of a Forest liaison within the Cultural Resources Management section of each Forest has been found to be an efficient and effective method for communication and consultation, several weaknesses and inadequacies still remain. First, few Forest Archeologists or their staffs have the skills of a professional ethnologist. Consequently, Indian concerns may be diluted or subsumed by purely archeological matters and the archeologists may not be able professionally to handle issues involving major conflicts with Indians. Also, the professional competency and reputation of the Forest can be called into question when archeologists do ethnographic work without suitable training or experience. In addition, most CRM sections are one or more years behind in meeting timber sale targets and do not have the time that is needed to provide meaningful consultation, and in a timely-enough manner to benefit long-term planning. Such inadequacies can be minimized by adding the position of Regional Ethnologist to the staff of the Cultural Resources Management section of the Regional Office.

The duties of such a person would be to provide training to the Forest liaisons, and to prepare policy items for adoption within the Region regarding access to information, security of information, professional ethics when conducting ethnographic research, and the rights or limitations of Indians for privacy and use of National Forest lands. Additional duties of the Regional Ethnologist would be to design and conduct continuing ethnographic research in consultation with those tribes having interests on National Forest lands within the Southwest. In keeping with the service role of Regional Offices, the Regional Ethnologist would provide assistance to the Forests for situations that involved multi-tribal consultations or particularly sensitive issues the Forest liaisons are not able to handle alone.

The full scope of duties for a Regional Ethnologist would include the following:

- to provide training to the Forest liaisons, and the tribal liaisons, if they wish, in intercultural communication;

- to provide guidance to Forest Planning on ways to incorporate Indian concerns and values into the Forest and project-planning process;

- to play a proactive advocacy role in the Forest Service for Indian concerns;

- to review information provided by the tribes and Forest Liaisons;

- to provide integrated consultation and information on issues of interest or concern to all tribes;

- to serve as a clearinghouse for multi-tribal or multi-Forest concerns;

- to identify tribal interests with respect to Forest Service activities;

- to collect information and disseminate it to Forest and tribal liaisons as well as Forest Service management;

- to provide research services and coordination for individual Forests;

- to ensure legal protection of sensitive and confidential information collected and curated by tribal and Forest liaisons;

- to provide education, training, and leadership on ethical issues and the need for confidentiality of information and informants among Forest and tribal liaisons;

- to assist in General Management Reviews of the Indian consultation and involvement programs of the Forests; and

- to promote interagency communication and coordination in Indian-related issues.

SUMMARY

The key elements in the program suggested here for adoption by the Southwestern Region of the U.S. Forest Service are as follows:

1. Interaction with Indian groups should be kept at the most direct level possible. This will normally be between a Forest and a specific tribe.

2. Effective communication is the key to ensuring timely and appropriate consultation and relations with Indian tribes. Each Forest should designate one person to be responsible for communication and coordination with Indian groups, and tribes should be encouraged to designate a similar liaison as a contact person for consultation purposes. Experience has shown that personal contacts, rather than formal letters, work best to provide for the needs of the Forest Service as well as the tribes.

3. Each Forest should designate one person to be responsible for communication and coordination with Indian groups.

4. The position of Regional Ethnologist should be established within the Cultural Resources section of the Regional Office to guide policies, Forest liaisons, and ethnographic research.

5. Comprehensive ethnographies of Indian uses and concerns should be assembled for National Forest lands. Interagency cooperation and funding of ethnographic overviews should be explored since such information is needed by more than a single agency. The dynamic nature of Indian cultural growth and change needs to be recognized. Ethnographic overviews need to be updated periodically to reflect such changes, similar data kept current, and Forest management apprised of cultural changes.

6. Information about Indian uses and concerns should be considered at the earliest possible stage in project planning.

APPENDIX I: STAFFING AND COST ESTIMATES

Alternative 1: Regional Ethnologist and Forest Liaisons

Regional Office

1 Regional Office Ethnologist, GS-11	$30,000
20% indirect costs	6,000
	$36,000

Forest Supervisor's Office

Approx 1/12 of Liaison's time to perform liaison function

GS-11 x 11 Forests x $2500/year	$27,500

Tribal Ethnographies

39 tribes x $30,000 each	$1,170,000
20% indirect costs	234,000
	$1,404,000

Total One-time Cost:	$1,404,000
Total Annual Cost:	$ 63,500
TOTAL COST (first year)	$1,467,500

Alternative 2: Ethnologist on Each Forest

1 Regional Ethnologist (includes 20% indirect costs)	$36,000
11 Forest Ethnologists (includes 20% indirect costs)	$396,000
39 Tribal Ethnographies at $36,000 each (includes 20% indirect costs)	$1,404,000

Total One-time Cost:	$1,404,000
Total Annual Cost:	$ 432,000
TOTAL COST (first year)	$1,836,000

APPENDIX II: RECOMMENDED ADDITIONS TO GS-193 PROFESSIONAL SERIES JOB DESCRIPTIONS FOR A REGIONAL FOREST SERVICE ETHNOLOGIST

1. Extensive training in ethnographic research methods.

2. Ability to train and supervise others in ethnographic research, data management, analysis, and the production of ethnographic reports.

3. At least two years of field work with at least two Indian communities in the Southwest.

4. A publication record that demonstrates familiarity with Southwestern Indian groups and ethnographic procedures.

5. A Ph.D. degree or suitable experience in sociocultural anthropology, including training in ethnohistory, history, and archeology.

6. Demonstrated ability to work amicably with Southwestern Indian communities.

APPENDIX III: PROPOSAL FOR NATIVE AMERICAN CONSULTATION RESEARCH

This research proposal has been prepared at the request of the Rocky Mountain Forest and Range Experiment Station to allow the Station to conduct research addressing the complex issue of improving communication between the Forest Service and Indian tribes in order to allow the Forest Service more effectively to manage all cultural resources on Forests in the Southwestern Region. The preparers of this research proposal do not believe this is the best way to develop an Indian-Forest Service program. As a result, the main document of which this appendix is a part has also been prepared. It outlines a program that we believe will be the most effective, cost-efficient, and productive course to increase tribal input into Forest Service management of Forest lands. This appendix should be read only in conjunction with the main document.

Mission

The purpose of the proposed research is to improve Forest Service management of cultural and other resources by obtaining timely, comprehensive, positive input from Native American groups.

Justification and Problem Selection

These are discussed at length in the main document, of which this appendix is a part.

Approach to Problem Solution

Three general problem-areas have been recognized that impede communication between Forest Service personnel and tribes, reducing the effectiveness of management decisions. Under each problem, several options are listed. It is recommended that each option be considered by gathering data to evaluate its effectiveness in providing information to managers or in reducing complaints by users. The data gathered by the research program should allow managers to choose which option is best. To facilitate the data gathering process, a sampling design of Forests and tribes is suggested for each problem.

Problem 1: Information about tribes is incomplete, inaccurate, and out-of-date.

The ethnographic portions of existing Forest Cultural Resources Overviews previously prepared by Forests must be reviewed by professional ethnologists, affected Indian groups, and professional archeologists. In order to make quick and accurate management decisions, it is necessary to have the most up-to-date, complete, and accurate information concerning all aspects of the potential impacts of management decisions. In the case of Indian uses, as well as Indian concerns for other activities on Forest lands, the existing information does not approach these standards.

The mechanism for obtaining information from tribes that will give managers the best data to make decisions must be determined. Three options should be considered:

1. Compile, summarize, and use existing ethnographies, ethnohistories, and historic documents. In some Forests this task may be subsumed under the Cultural Resources Overview(s).

2. In addition to item (1), conduct interviews of tribes by ethnographers.

3. In addition to item (1), contract to have tribes do their own ethnographies.

Test and define the best methods for obtaining the data from tribes regarding their uses of a Forest by evaluating the effectiveness of the programs on one Forest using four tribes.

<u>Accomplishments Planned for the Next Five Years</u>.

<u>Year 1</u>

1. Completion of peer and tribal review process for existing documents, including Cultural Resources Overviews of five forests.

2. Choose four tribes from selected Forests on which to conduct ethnographies.

a. Two tribes will do their own ethnographies and two will be studied by ethnographers.

b. The Cultural Resources Overviews will provide the framework for the ethnographies.

c. The studies should utilize the guidelines specified earlier in this document for the nature of the data collected by the ethnographic studies to ensure their utility to Forest Service management.

<u>Year 2</u>

1. Complete the ethnographies conducted by USFS and by tribal ethnographers.

Year 3

1. Conduct peer review of the ethnographies

2. Conduct USFS management evaluation of the ethnographies and syntheses.

Year 4

1. Test management recommendations as defined by the management syntheses.

Year 5

1. Test management recommendations

2. Evaluate the results.

Problem 2: Input addressing tribal concerns is solicited too late in the land management and project-planning process

Although the Forest Service has ten-year, five-year, three-year, and other planning cycles for management of resources, input on the impact of these management plans on Indians is almost never solicited until well into the planning process. At the present time, it is difficult to determine when Indian input can be most effective because project locations, size, and intensities become more specific as the planning process progresses. Is there a point where available information does or does not provide for adequate dialogue between the Forest Service and Indian tribes?

For most effective management, when is it best to get input on tribal concerns into the project development process? Options for the timing of tribal consultation include: (1) the initial planning stage only; (2) the planning refinement stage only; (3) the planning completion stage only; (4) the implementation stage only; or (5) at all stages. We propose to test the efficacy of these options on five Forests.

Accomplishments planned for the next five years

1. Incorporate and evaluate the efficacy of tribal input at each stage of the project planning process.

2. Test management recommendations based on each process.

Problem 3: Responsibility for coordinating Indian input and concerns is fragmented within the Forest Service, severely inhibiting the ability of managers to obtain meaningful input from Indian clients

Present Forest Service structure usually places responsibility for coordinating contacts with tribes within the Cultural Resources section under the direction of the Forest Archeologist. Generally, the Forest Archeologist lacks the skills, training, and time to coordinate effectively Indian issues generated either through legislative mandates, unsolicited tribal concerns, or planned Forest Service projects. It is necessary to determine the best mechanism for assigning responsibilities for Indian contact and to obtain input from tribes.

For this a new job duty - a Forest liaison to coordinate Indian concerns and contacts - will be tested on five Forests. Various ways of assigning liaison responsibilities will be tested in various units of the test Forests. These will include establishing the liaison (1) as a new Forest function at the Staff level; (2) as a new responsibility of a cultural resources specialist; (3) as a new position within the Cultural Resources section; (4) as a new responsibility of a land management planner; or (5) as a new position within Land Management Planning.

Accomplishments planned for the next five years

Year 1

1. Evaluate the effectiveness of existing Indian coordination program on each Forest.

Years 2 - 5

1. Compare the effectiveness of the five models to the existing program and to each other.

Staffing and Cost Estimates

It is assumed that the Research Station scientist who coordinates the research projects will be a GS-11 position (approximately $30,000 per year) assigned half-time to this program over a period of five years with a 20 percent support (overhead) cost.

Research Scientist, GS-11, 1/2 time	$15,000
20% support	$ 3,000
TOTAL	$18,000/year
TOTAL COST: $18,000/year for 5 years	$90,000

Problem 1

Basis of Cost Estimate

Review of existing Forest Cultural Resources Overviews:

35 days @ $200/day	$ 7,000

Ethnographies: contract at cost of $30,000 each with 20 percent support costs

$30,000 each x 4	$120,000
20% support	$24,000
TOTAL COST:	$144,000

Peer Review of Completed Ethnographies: contract at $3,000 each with 20 percent indirect costs

$3,000 each x 4	$12,000
20% indirect costs	$ 2,400
TOTAL COST:	$14,400

Forest Service review of ethnographies

Various personnel. Assume	$12,000

Forest Service testing of recommendations

Various personnel. Assume	$15,000/year

Forest Service evaluation of results

Various personnel. Assume	$15,000/year

Annual Costs

Year 1: Review of Overviews	$ 7,000
Year 2: Contract for Ethnographies	$144,000
Year 3: Contract peer review of Ethnographies	$14,400
Forest Service review	$12,000
TOTAL (year 3)	$26,400
Year 4: Forest Service review	$15,000
Year 5: Forest Service review	$15,000
Forest Service evaluation	$15,000
TOTAL (year 5)	$30,000
TOTAL COST FOR PROBLEM 1	$222,400

Problem 2

The five test Forests receive $ 2,000/year to assemble and provide the necessary information.

5 Forests x $2,000/year x 5 years	$50,000
TOTAL COST FOR PROBLEM 2	$50,000

Problem 3

Basis of Cost Estimate

New Staff-level GS-12 Liaison	$36,000
20% indirect costs	$ 7,200
TOTAL	$43,200
Existing or new GS-11 Liaisons	$30,000
20% indirect costs	$ 6,000
TOTAL	$36,000

Forest Service review of effectiveness of existing Indian coordination programs. Various personnel. Assume $15,000

Annual Costs

Year 1: Evaluate existing programs	$15,000
Year 2: Implement and compare the models	$187,200
Year 3: Implement and compare the models	$187,200
Year 4: Implement and compare the models	$187,200
TOTAL COST FOR PROBLEM 3	$576,600

A summary of cost estimates for Projects 1, 2, and 3, by year, is given in Table 1.

Table 1.--Yearly cost estimates for research projects 1, 2, and 3.

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Research Scientist	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 90,000
Problem 1	$ 7,000	$144,000	$ 26,400	$ 15,000	$ 30,000	$222,400
Problem 2	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 50,000
Problem 3	$ 15,000	$187,200	$187,200	$187,200	-	$576,600
TOTAL COSTS:	$ 50,000	$359,200	$241,600	$230,200	$ 58,000	$939,000

Areas and Issues in Future Research on Archaeological Resource Protection[1]

Martin E. McAllister[2]

Abstract.--The magnitude of the archaeological resource protection problem in the United States is briefly described and the lack of knowledge on the nature of this problem is discussed. Potential areas for future research on the problem are suggested, as are important research issues under each area.

INTRODUCTION

Most archaeologists recognize that a serious archaeological resource protection problem exists in the United States today. Even though nearly 10 years have elapsed since the passage of the Archaeological Resources Protection Act (ARPA), sites are still being looted and vandalized at an alarming rate on Federal lands and sites on state and private property continue to be targets as well. The magnitude of the current protection problem is only beginning to be quantified.

In the recent General Accounting Office (GAO) study entitled "Problems Protecting and Preserving Federal Archeological Resources" (1987), it was learned that an estimated 32 percent of the known sites on National Park Service, Bureau of Land Management and Forest Service lands in the Four Corners area of Arizona, New Mexico, Colorado and Utah were recorded as being disturbed by looting. In addition, another 33 percent of the known sites there are potentially affected by looting and vandalism since they are listed in the agencies' inventories as being in an unknown condition. Only 35 percent of the known sites are recorded as undisturbed and even many of these may have been damaged since they were inventoried or last inspected.

Also disconcerting were the GAO's findings on the frequency of looting and vandalism in the study area. According to the figures presented, documented incidents on lands of the three agencies in the Four Corners area totaled 1,222 between October 1, 1980 and March 31, 1986. This means that there were an average of approximately 222 reported incidents per year there or between 18 and 19 per month. The actual total figure for instances of looting and vandalism and the number per year and per month would, of course, be much higher if known.

Beyond the Four Corners states, documented violations involving archaeological looting and vandalism have occurred between 1979 and 1988 in at least 11 other states, Alaska, California, Oregon, Idaho, Wyoming, Minnesota, Arkansas, Illinois, Kentucky, Virginia and Florida, as well as in the District of Columbia. The most recent in California and Kentucky were particularly severe. In California, 19 individuals have been assessed civil penalties for looting at four submerged historic shipwrecks located in Channel Islands National Park and National Marine Sanctuary. The incident in Kentucky took place when 10 individuals leased a large prehistoric site on private property in which they dug approximately 400 holes disturbing between 1,000 and 1,200 burials. They have been indicted for violating a state statute which prohibits the desecration of graves. From information such as this, it can be concluded that the serious looting and vandalism problem documented by the

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[1] Paper presented at the symposium, Tools to manage the past: Research priorities for cultural resources management in the southwest. [Grand Canyon, Arizona, May 2-6, 1988.]

[2] Martin E. McAllister is an archaeologist and the owner of the firm of Archaeological Resource Investigations, Laona, Wisconsin.

GAO in the Southwest also continues to occur on a nationwide basis.

Despite some improvement in our knowledge of the extent, frequency and distribution of archaeological looting and vandalism in the United States, the position taken here is that we still know relatively little about the nature of the problem itself. There has been very limited analysis of the causes and characteristics of looting and vandalism and also neglected are formal evaluations of the effectiveness of current and potential solutions to the problem. The work which has occurred is inadequate relative to the scope of the situation which now exists. If we had analyzed the problem to the extent that we need to, then surely we could apply our findings to reduce the amount of looting and vandalism occurring.

The goal of this paper is to suggest areas and issues which appear to need further research and study in order for us to more fully understand why and how archaeological looting and vandalism occur and to develop effective and workable strategies for their prevention. Two categories will be addressed, the areas and issues which should form a background to the analysis and those which should be primary components of research on archaeological resource protection. The potential to actually carry out the research suggested from financial or other administrative standpoints will not be a concern here. The purpose is to identify what should be known from an ideal perspective.

BACKGROUND AREAS AND ISSUES

One serious shortcoming in the analysis of the archaeological resource protection problem which has occurred to date is that it has been carried out in a research vacuum. Archaeological looting and vandalism on public lands are types of illegal, anti-social behavior no different in their basic criminality than other forms of public property theft and defacement. Yet, we have tried to deal with them as if they were unique types of activities and not encompassed by the discipline of criminology. This situation can be rectified by reference to research on at least three areas in the study of crime. These are vandalism as a category of criminal behavior, the prevention of vandalism and general crime prevention.

Vandalism and Vandalism Prevention

Current research in these areas obviously should have a high degree of relevance to archaeological resource protection. Knowledge of this research would provide information on at least three important issues.

Willful acts of damage or defacement carried out for the intrinsic purpose of destroying archaeological resources are directly analogous to property vandalism of all types. It follows that what has been learned about the causes and characteristics of other forms of property vandalism should be a subject which will help to inform us about archaeological vandalism. For example, vandalism expert James Wise identifies proximity as one factor in this activity in situations parallel to those involving archaeological sites:

> In a recent survey of vandalism at outdoor recreation facilities, 80 percent of stolen or user-damaged items were within reach of 95 percent of passers-by (1982:34).

An issue which also should be considered is whether there are forms of vandalism involving theft that closely resemble archaeological looting. If there are, then what is known about these types of vandalism should be of definite interest in dealing with the looting problem.

The other major issue of concern is identification of the prevention methods which either are under study or are already being used effectively in combating the various types of vandalism, particularly any which have been found to be very similar to archaeological vandalism or looting. An example of such a strategy, limiting access to property as a means of preventing vandalism, has been described by Wise as follows:

> Easy targets are the most likely to be vandalized. In a park near Seattle, light fixtures that overhung a path were broken repeatedly. The path led to baseball diamond, and the glass globes were just within bat reach of exuberant, or dejected, players on their way home. Rotating the globes upwards 180 degrees put them out of reach, and stopped the breakage (1982:34).

Archaeologists have considered controlling access to archaeological sites

as a means of preventing looting and vandalism, but few if any studies have been carried out to determine if the strategy will actually work. By reference to the literature on current research on vandalism such questions can be answered, at least by analogy.

Crime Prevention

In the area of crime prevention there are several issues which should be addressed. As a starting point, there is a need for those concerned with archaeological resource protection to become familiar with the general theories of crime prevention under which the criminal justice system in the United States currently operates. The prevention of archaeological resource crime should be based on state-of-the-art knowledge in this area and not on outdated or unsupported theories. Since current approaches to the problem appear to derive primarily from what criminologists refer to as deterrence theory, critical concerns should be the concept and principles of this theory and the extent to which deterrence is currently accepted as an effective means of crime prevention. Also studied should be other conformity producing mechanisms supported by recent research in criminology and how they are seen to operate in relation to deterrence.

A brief introduction to the theory of crime prevention will illustrate the importance of the issues raised to archaeological resource protection. While not based on an exhaustive review of current research, the findings cited here should demonstrate the need for further knowledge of the work of criminologists.

Writing recently on the underpinnings of general and individual deterrence theory, three recognized experts on criminology, David P. Farrington, Lloyd E. Ohlin and James Q. Wilson, could have been describing the movement to enact ARPA:

> When the legislature wishes to raise the level of the publicly perceived moral culpability of an offense, it will frequently attach to its denunciation of the act a new option of imprisonment as a sanction or extend the maximum allowable sentence to prison . . . Use of the threat of confinement in this way is premised on the assumption that the social disgrace and deprivations of imprisonment have a powerful general deterrent effect on potential offenders. It is also assumed that the experience of imprisonment will help deter the individual offender from repeating his offense in order to escape further confinement (1986:135).

This might make it appear that the drafters of ARPA were on firm ground in the theory of crime prevention until it is learned that Farrington, Ohlin and Wilson go on to evaluate the current status of evidence supporting the deterrence model as follows:

> Considering the pervasiveness of these deterrent assumptions embedded in the criminal law, it is remarkable how little evidence can be assembled to document these assumed effects (1986:136).

One aspect of deterrence theory which does seem to be generally accepted according to Farrington, Ohlin and Wilson is the effect of certainty of enforcement:

> In general, . . . effective deterrence is linked to the public perception of the certainty of enforcement . . . Apparently an unenforced threat lacks the credibility to deter (1986:136).

Other criminologists also agree with this principle, as can be seen from W. William Minor's discussion contrasting the deterrent effect of certainty of enforcement or punishment with that of severity of sanction:

> The most consistent finding in deterrence research is that higher levels of certainty of punishment are associated with lower levels of crime. This pattern has been regularly reported in experimental studies . . . , in studies relating sanction structures to crime rates across different different jurisdictions . . . , and in studies relating individual perceptions of sanctions to self-reported criminality . . . The impact of severity of sanctions is much less clear, however. Various studies have found no apparent deterrence attributable to severity . . . , an apparent deterrent effect only for certain types of crimes . . . , or a deterrent effect of severity only at certain levels of certainty (1978:25).

Minor makes another important point concerning the deterrence model:

With few exceptions, deterrence theory and research have been characterized by . . . a tendency to ignore conformity- and deviance-inducing devices other than deterrence (1978:29).

Minor sees deterrence as only one aspect of the larger "control theory" of crime prevention. According to his description of this theory, it distinguishes between conformity producing controls or sanctions which are "formal (i.e. legal) and officially administered" and those which are "informal and imposed by significant others (e.g. family or peers)" (1978:25), also referred to as "extralegal" sanctions (1978:30).

Criminologist Robert F. Meier also emphasizes the importance of alternatives to deterrence:

. . . Legal threats are only one part of the overall web of social control efforts, and . . . the potential impact of legal threats cannot be appreciated fully without explicit consideration of this larger context (1978:223).

. . . They may not be as important controls as other (extralegal) influences . . . Even if research were able to identify fully the conditions under which legal threats deter, and if such conditions were changeable to maximize deterrence, the subsequent reduction in crime may be negligible if other factors remain unchanged (1978:235-236).

One informal, extralegal control considered by Meier involves risk perception as opposed to actual certainty of enforcement or punishment:

A number of social control efforts have attempted to increase the perceived risk to potential deviants . . . The policy point is that if the primary goal of manipulating a control structure is to achieve a deterrent effect, one possible way to accomplish this goal is to lead the potential deviant to over-estimate the degree of control and risk in committing the act (1978:241).

. . . The goal is to manipulate the perception of potential offenders of the risk of deviance, rather than trying to change objective risk (1978:242).

More basic extralegal controls are the society's moral standards. In this regard, Farrington, Ohlin and Wilson point out that:

. . . orderly society rests more securely on the internalization of moral standards and defenses against crime than on externally enforced sanctions (1986:136).

Another expert, Joan E. Jacoby, has elaborated on this point as follows:

. . . Deterrence from criminal activity may be due more to the normative values of the community, church, school, peers, or economic institutions than to the punishment likely to be invoked by the criminal justice system. The power of social control relative to the controls of criminal law affects a wider population than does the imposition of criminal penalties (1978:139).

Concerning the effects of legal versus extralegal sanctions in crime prevention, Minor notes that:

In studies which have directly compared these effects . . . , informal sanctions have been shown to be considerably more potent (1978:25).

It would appear, then, that the apparent failure of the more severe sanctions of ARPA to significantly deter looting and vandalism of archaeological sites could be at least partially attributed to the operation of two basic principles which have emerged from research on crime prevention. First, problematic aspects of ARPA, such as the $5,000 felony/misdemeanor distinction, have made certainty of enforcement of the law impossible so that its sanctions have not had the desired deterrent effect. Second, by assuming that a law with more severe sanctions would automatically solve the problem, deterrence has been emphasized at the expense of other extralegal controls.

Had the drafters of ARPA been more conversant with the work of criminologists on the theory of crime prevention, their emphasis on increasing the severity of the Antiquities Act's penalties might have been more prudently directed toward a concern for ensuring that the new act's prohibitions could be easily enforced. The same knowledge might also have led archaeologists and managers to devote more attention to extralegal approaches such as efforts to increase the risk perception of those engaged in looting and vandalizing archaeological sites and

programs designed to create or re-establish informal sanctions against the inherent immorality of these acts.

As familiarity is gained with the literature on criminology, we may need to consider whether there is a need for further revision of ARPA and current approaches to enforcement of the criminal provisions of the act. A working knowledge of the theory of crime prevention should certainly be acquired if the effectiveness of archaeological resource protection is to be enhanced in the future.

PRIMARY AREAS AND ISSUES

There are a number of factors directly associated with archaeological looting and vandalism which will require further research if we are to fully understand the nature of the archaeological resource protection problem. The primary research areas identified here are looting and vandalism behavior, the artifact trafficking network, public attitudes toward looting and vandalism, site risk factors, the extent and distribution of looting and vandalism, protection enforcement, protection training and site protection programs.

An obvious initial step in conducting future research in all of these areas would be to determine the current status of knowledge on each. As was pointed out earlier, little work has been done on the nature of the archaeological resource protection problem, however some studies do exist for certain of the areas listed. All of these studies should be identified, consulted and utilized to the extent possible in future research.

Looting and Vandalism Behavior

The behavior causing the archaeological resource protection problem must be understood if it is to be prevented. Working from this premise, a crucial research area will be determining why looting and vandalism behavior occurs.

A basic issue should be the identification of factors which motivate individuals who engage in either the looting or vandalism of archaeological resources. Several specific research questions can be suggested which would be pertinent to this topic. Is the concept of hobbyists inspired by personal interest versus commercial looters driven by the potential for profit valid as a basic distinction in the causes of archaeological looting? Are other motivating factors involved in looting? What provokes individuals who vandalize archaeological resources?

Following the isolation of basic causal factors should come further research to address the issue of identifying individuals or groups who are likely to engage in either the looting or vandalism of archaeological resources. Some specific research questions appropriate at this point would be the following. Can any distinctive socio-economic characteristics be associated with a proclivity for either looting or vandalism behavior? Are there any other identifiable individual or group characteristics which can be linked to either proclivity, such as sex and age? Is it possible to generate looting and vandalism profiles and, if so, at what geographic level, local, regional or national?

An additional issue related to the possibility of generating profiles beyond the local level is the existence of any significant regional variations in looting and vandalism behavior. Are there distinctive regional patterns of looting and vandalism behavior which deviate significantly from those in other areas? If so, are they different only in terms of the resources affected or do they diverge in other more important aspects of the behavioral patterns, such as basic motivating factors and the characteristics of those involved?

There should be a number of types of behavioral research which would address these issues and questions in the area of archaeological looting and vandalism behavior. If such research were to be carried out, experts on behavioral research in sociology would have to be involved to determine the best analytical methods to employ. Several potential directions can be suggested here. First, there should be systematic efforts to study individuals known to be looters or vandals. This would involve research on their backgrounds and interviewing if they would cooperate. Second, sociological survey research on motivational and demographic factors in archaeological looting and vandalism should be carried out targeting recreation users of public lands. Third, whenever possible, questions on archaeological looting and vandalism behavior should be included in other survey research projects.

The Artifact Trafficking Network

Also critical to archaeological resource protection is the larger context in which looting behavior occurs. At

present, it is known from law enforcement investigations that a regional and national trafficking network in artifacts exists. Its basic components are the artifact procurers, the hobbyists and the commercial looters, who provide the supply, the collectors who generate the demand and the dealers who are the middlemen.

Still to be analyzed is the more complex issue of the actual organizational structure of the network. A number of examples of specific concerns for future research can be listed. To what extent do artifacts originally procured by hobbyists find their way into commercial trafficking and in what ways? Do hobbyists become commercial looters and how frequently? Are the majority of commercial looters also collectors? What percentage of commercial looters earns the majority of their income by looting? How common is it for commercial looter to also act as dealers? What are the links between the local, regional and national components of the network that allow artifacts to move from where they are procured to higher level markets? What are the principal regional and national trafficking centers? How is domestic trafficking related to the international artifact market?

To answer organizational questions such as these, interview and survey research would have to be carried out targeting individuals who have knowledge of the various levels of the artifact trafficking network and how they interact. It is likely that the most important sources of information would be dealers operating out of regional and national trafficking centers. Difficulties which could be anticipated are a lack of cooperative informants on the overall structure of the network and resistance to revealing vital organizational details. The research proposed on looting behavior also should provide some insights on how individuals become involved in the larger trafficking network.

Public Attitudes Toward Looting and Vandalism

As was suggested earlier in considering crime prevention theory, a negative public attitude regarding archaeological looting and vandalism should be extremely important in preventing these acts. For this reason, definition of the current public attitude is a critical research area. Some criminologists argue for a basic perceptual distinction in the public or societal view of criminal behavior (Minor 1978). According to these experts, laws have greater deterrent power when they prohibit crimes regarded as "mala in se" or, in other words, inherently bad or immoral because they violate the society's moral code. Laws with less deterrent effect apply to crimes seen as "mala prohibita" or simply illegal but not immoral. From this standpoint, an initial research issue to be addressed would be how the public regards looting and vandalism of archaeological resources in terms of the two perceptual categories of criminal behavior. If it is found that these activities are viewed as simply illegal under ARPA and other laws and regulations, but not as inherently immoral transgressions of our moral code, then it would appear that prevention will be more difficult until this attitude is reversed.

Other specific attitudes of the public concerning archaeological looting and vandalism should also be an important research issue. Examples of pertinent research questions deriving from this issue are easily generated. Since Native American sites and artifacts are a principal target, what are the attitudes of the members of the various tribes and groups concerning looting and vandalism? Although it can be predicted that their outlook would be generally negative, it would be useful to know what specific views are prevalent. Does the majority of the public feel that looting and vandalism of archaeological sites should be illegal on Federal and state lands? Are there any circumstances under which they feel such activities should not be prohibited? What is the public attitude regarding appropriate levels of punishment for archaeological resource crime? How do they view looting and vandalism in relation to other types of crime? Obviously, the statistical weight of the specific public attitudes identified in relation to population size would be as critical as the attitudes themselves. Also important would be the recognition of any significant regional variations in public attitudes regarding archaeological looting and vandalism.

Formal sociological survey research should be carried out to further define the general public attitude toward archaeological looting and vandalism. Again, as with the survey research recommended on looting and vandalism behavior, it would be necessary to consult the experts in this field to design the best types of analytical approaches to data gathering and interpretation.

Site Risk Factors

This is an extremely important research area in designing effective prevention and enforcement programs for future archaeological resource protection. Unfortunately, it has been neglected since the early 1980's when a few regional studies of site risk were carried out.

The basic issue should be to determine what site characteristics and other associated factors increase susceptibility to looting and vandalism and, if so, the degree to which they affect risk. Based on past research, some variables which should be analyzed in relation to looting are: site type, site size, types of artifacts present, types of features present, presence, type and amount of previous unauthorized disturbance, type of physical access allowed to the site, presence and type of signs, presence and type of other physical protective measures, distance to trails, distance to roads, distance to private property and distance to towns. Any other factors which increase the risk of looting also should be identified, as should those causing greater susceptibility to vandalism. Regional variation in site risk proclivities also would be an important concern in future research.

A major research effort to address these issues would involve a number of important components. Each state should develop a site risk analysis system to identify and measure the factors which significantly increase susceptibility to looting and vandalism in that geographic area. Regional consistency in analysis systems would be highly desirable. Using existing site inventory records as the initial data base, studies should be conducted to identify all known looted and vandalized sites in each state. When the affected sites are identified, inventory information on them should be subjected to the risk analysis developed. Newly recorded sites in each state found to be looted or vandalized also should be analyzed as part of their accession into site inventory files. This ongoing analysis should result in refinement of the overall identification of site factors which increase risk. Each state should publish an annual report on the results of the site risk analysis conducted during the year. State results should be integrated regionally and nationally to determine what common factors in site risk exist at those levels.

Extent and Distribution of Looting and Vandalism

The lack of substantial knowledge in this research area is a serious handicap in our understanding of the full magnitude of the archaeological resource protection problem. For this reason, data gathering on the extent and distribution of looting and vandalism also should assume a high priority in future research efforts.

A basic issue which should be resolved in order for data gathering to proceed effectively would be to determine if the routinely utilized variables in the limited studies already conducted provide accurate extent and distribution assessments on a regional and national basis. In addition to locational information, these generally include total number of sites recorded, number and percentage of recorded sites which are looted or vandalized, number and percentage of recorded sites which are undisturbed, and number and percentage of recorded sites which are in an unknown condition.

It can be argued that assessments based on total numbers of sites in each gross category without some baseline discrimination of site characteristics do not reflect the true extent of disturbance affecting some site types. Some site related variables which could be considered for inclusion in these assessments might be identified as a result of the site risk analysis proposed above. Agreement on the relevant variables and how they are to be distinguished should be reached regionally and also nationally if possible.

Ideally, uniform data on the national extent and distribution of looting and vandalism should be gathered. One potential strategy to accomplish this end would be to develop a national form for documenting looting and vandalism of archaeological sites. The form should be brief, not exceeding one page in length, and should be utilized in conjunction with all agency and private institution inventory forms. It should be completed for all newly recorded sites which are disturbed and also for affected sites in existing inventories.

Created in conjunction with the documentation form should be a national computerized data bank for the information accumulated through the use of the form. The prototype for such a data bank

already exists in the Department of the Interior's Listing of Outlaw Treachery or "LOOT" clearinghouse maintained by their Archaeological Assistance Division in Washington. This computer data base is currently designed to accumulate information on cases involving prosecutions for archaeological violations, but perhaps it could be expanded to become the overall national data bank for documentation of site looting and vandalism.

Protection Enforcement

Reliable national statistics are also lacking in this area. If archaeological protection enforcement is to be improved, data should be available on the effectiveness of efforts which have occurred to date throughout the country. The two principal issues of interest would appear to be, first, statistics for cases in which charges were filed or citations were issued and, second, those for incidents where actual or potential violations were documented but no further action was taken. Included should be data for all agencies with responsibility for enforcing Federal, state, local and tribal laws or regulations which specifically protect archaeological resources or which have general prohibitions applicable to archaeological resources.

As part of the LOOT clearinghouse project, a case summary form has been developed. Categories of information requested on the form are: agency, region, state, location, defendant or defendants, incident date, arrest date, indictment date, information date, hearing date, trial date, plea and date, judgment and date, sentence and date, was there forfeiture and, if so, the amount in dollars or the items forfeited, fine imposed, contact name, telephone number, and narrative summary. Information gathering using this form, data analysis and dissemination of summary statistics to participating agencies are already in progress.

This research effort should continue and be expanded beyond the Federal agencies now contributing information to include all appropriate state, local and tribal agencies as well. The form should be used to record current and future cases involving charges or citations as well as all other documented violation incidents. In addition, the participating agencies should review their records to identify all past cases and incidents which have occurred in their jurisdictions. The logical date to use as a starting point for data gathering would be either 1906 or 1979. Beginning with the earlier date would be more difficult and pre-1970's data would often lack complete reliability. The advantage of attempting to include the older information would be to provide a baseline for evaluating the success of later enforcement. Once recorded in the LOOT clearinghouse format, the case and incident information should be submitted to the Archaeological Assistance Division data bank in Washington where it would be subjected to the already occurring data analysis and dissemination process.

Protection Training

This effort has received much attention as an approach to dealing with the looting and vandalism problem. Many law enforcement officers and archaeologists have attended 40 hour training programs on archaeological protection taught regionally by various Federal agencies since 1979 and by the Federal Law Enforcement Training Center (FLETC) on a nationwide basis since 1983. To date, however, there has been no formal, national research to evaluate the extent of this training or its effectiveness. Efforts to improve the availability and quality of archaeological protection training in the future should be based on such an assessment.

Basic information required in this research would be the number of law enforcement officers and archaeologists per agency who have completed FLETC's Archaeological Resource Protection Training Program or another equivalent Federal 40 hour training program. Since 1987, FLETC has offered a separate 16 to 20 hour block of instruction on archaeological protection as part of its Land Management Investigation Training Program, so the trainee figures for this or other similar Federal courses also should be obtained. Based on these numbers, the percentages of law enforcement officers and archaeologists per agency who have received training could be calculated.

Statistical measures of the effectiveness of the training would need to be designed also. Two relevant indices might be, first, the number of law enforcement officers and archaeologists per agency who feel they have prevented one or more archaeological violations since completing the training and, second, the corresponding totals for those who have subsequently been involved in the actual investigation of one or more cases. Also important would be the percentage of these investigations which have resulted in successful prosecutions. In addition, all participants in the programs could be

asked to provide written comments on the effectiveness of the training. To conduct this research, it would be necessary to obtain student identification information from FLETC for the Archaeological Resource Protection Training Programs and the Land Management Investigation Training Programs taught since 1983 and 1987 respectively. In addition, other Federal agencies should be requested to provide such information for any equivalent 40 hour or 16 to 20 hour training programs offered since 1979. A questionnaire also would have to be developed to acquire data and written comments to measure the success of the training.

Site Protection Programs

A number of programs of this type exist, ranging from minimal to intensive in the level of protection provided. They are managed by Federal, state, county and municipal government agencies, tribal groups and even amateur historical or archaeological societies and other private concerns in some instances. At present the details of some of the more sophisticated programs are generally known, at least on a regional basis, but there has been no systematic, nationwide study of site protection methods currently in use.

To address this issue, a national survey of existing protection programs should be conducted. Ideally, the research would seek to obtain basic information on all such programs throughout the United States, including location, site characteristics, protection features and length of time in operation. Also sought should be some appropriate indication of actual or estimated effectiveness in preventing looting and vandalism of the site or sites at each location. From the data gathered, there should be an attempt to produce an overall ranking of the protection methods currently employed in various situations, depending on factors such as the nature of the location and the number of sites involved.

Also needed is research designed to actually test the application of certain protection strategies. This could be carried out by monitoring their application to sample high risk sites in a geographic area while leaving other similar sites in the same area in an "as is" condition as a control. Tested in this fashion might be site signing, posting written closure orders on sites, physically restricting entrance, closing access roads or trails to sites, reducing the visibility of project management related site marking, removing all diagnostic and collectible artifacts from site surfaces, restoring all previously damaged areas, and patrolling by law enforcement officers on a regular basis. The use of many of these methods has been debated for years without attempting to determine if they actually achieve the desired protection effect.

There are also various experimental approaches to protection which should be more fully evaluated in the future. Examples of such programs are the complete excavation of high risk sites using volunteers as the field and laboratory labor force, the opening of archaeological laboratory and curation facilities to the public on a regular basis, temporary loans of display quality artifacts to individual members of the public under controlled conditions and sentencing convicted looters and vandals to work as laborers in stabilization and restoration activities or other archaeological projects. The prevention effect of experiments such as these could be evaluated by monitoring the condition of sites in the surrounding area during the time that the pilot program is implemented.

An additional issue, and perhaps the most important suggested here, is the use of public education as a direct site protection strategy. Vandalism experts are already conducting experiments on how various public education techniques can create what they refer to as "pro-social" behavior toward archaeological sites in order to prevent visitor damage (Chistensen in press; Gramaan et al. in press). More research of this type should occur to determine the range of educational activities that will function as informal, extralegal controls to achieve site protection and to evaluate their relative effectiveness in preventing looting and vandalism. Archaeologists should become more directly involved in this effort and contribute their expertise where needed. This will be an extremely significant issue in future research since public acceptance of responsibility for archaeological resources may well be the ultimate answer to the looting and vandalism problem.

CONCLUSIONS

An attempt has been made to identify some of the more important areas and issues for future research on the nature of the archaeological resource protection problem. Other critical concerns undoubtedly exist which have not been addressed here. As was stated earlier, the major

purpose has been to indicate how little we actually know about the problem at the present time.

There is reason for both optimism and pessimism in this regard. Some of the research suggested is already under way or could be carried out with relative ease and without excessive expense. On the other hand the national level research efforts proposed would require a great deal of time and money to accomplish. Whether they could be funded and carried out in the foreseeable future is highly questionable. Perhaps the logical compromise position would be to begin these projects at the regional level and postpone national integration until later.

Whatever approach is adopted, we can expect that efforts to substantially reduce the looting and vandalism of archaeological resources will be of limited effectiveness until further research is accomplished. The problem will not be solved until it is more completely understood.

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Cultural Resource Protection: a Predictive Framework for Identifying Site Vulnerability, Protection Priorities, and Effective Protection Strategies[1]

Harriet H. Christensen[2], Ken Mabery[3], Martin E. McAllister[4], and Dale P. McCormick[5]

Abstract.-- Research is proposed to develop and test a predictive framework which Federal land managers can apply in cultural resource protection. Information is needed on four critical factors: site characteristics, value differences toward cultural resource management, motivations for theft and defacement, and effective site protection strategies.

INTRODUCTION

Federal land managers have limited personnel and funds to accomplish many programs mandated by Congress, one of which is cultural resource protection. Thousands of cultural resource sites have been recorded on Federal lands in the Southwestern United States, and more are discovered daily. It has been estimated, for example, that only seven percent of the sites on Federal lands in the Four Corners area have been found and recorded (General Accounting Office 1987). Many of the recorded and unrecorded sites are targets for unauthorized disturbance, including the looting and theft of artifacts and other types of defacement, but only a few known sites have been protected through law enforcement activities or other measures (Downer in press; McAllister in press; Nickens et al. 1981; Waldbauer in press). The majority are unprotected.

The recent General Accounting Office (GAO) report (1987) was highly critical of all aspects of the Federal cultural resource protection program in the Four Corners region. The GAO found that approximately 43,848 cultural resource sites, or nearly one-third of those recorded on Federal lands in the area, have been damaged by theft or defacement to some degree. However, between 1980 and 1986, only 1,222 incidents of cultural resource theft or defacement were documented by the region's Federal land management agencies, and only 27 cases produced convictions under the Archaeological Resources Protection Act. These figures indicate that current protection strategies are not effective in combating cultural resource theft and defacement.

If cultural resource preservation was the only concern in Federal land management, it would be desirable to apply some form of protection against theft and defacement to all known sites. However, it is clear that available funding and other management goals will not permit full protection of all cultural resource sites on Federal lands. Agency land managers are increasingly faced with hard questions. What sites do we protect and how

[1] Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2] Harriet H. Christensen is a Research Social Scientist for the USDA Forest Service, Pacific Northwest Research Station, Seattle, Washington.

[3] Ken Mabery is Chief Ranger, National Park Service, El Malpais National Monument, New Mexico.

[4] Martin E. McAllister is an archeologist and the owner of the firm of Archaeological Resource Investigations, Laona, Wisconsin.

[5] Dale P. McCormick is Resident Special Agent with the USDA Forest Service in Flagstaff, Arizona.

do we protect them effectively? It is critical that managers have some documented and supportable means by which they can assess relative protection priorities for known sites and reassess priorities as new sites are recorded.

PROPOSED RESEARCH

Frameworks have been developed to determine relative natural resource and ecological protection needs on public lands (Hoose 1981; United States Department of the Interior 1982). These frameworks have been modified by some Federal land managers to meet local cultural resource protection needs, but the thoroughness and effectiveness of the resulting criteria have not been formally evaluated, and remain in question for application beyond the level at which they were developed.

The goal here is to propose research to develop and test a framework specifically designed as a tool managers can apply to assess cultural resource vulnerability, prioritize sites for protection, and select effective protection strategies. The resulting evaluative criteria must be designed to rank site vulnerability on an ongoing basis and to assign higher protection priorities and the most effective protection strategies to the most vulnerable sites.

Overall management rankings of cultural resource sites will depend on a variety of factors such as importance to Native Americans, prehistoric and historic research values, and susceptibility to natural or management impacts (see the papers on these topics elsewhere in this volume). In order to develop a predictive framework for site protection, information is needed in four critical areas: site characteristics which affect vulnerability, value differences toward cultural resource management, motivations for theft and defacement, and evaluation of effective site-protection strategies.

The initial focus of the proposed research will be cultural resource sites managed by the USDA Forest Service in the agency's Southwestern Region (Arizona and New Mexico). At the same time, it will be desirable to develop a framework which is flexible enough in scope to allow future utilization by other Federal land management agencies in the Southwest.

Site Characteristics

Certain physical characteristics of cultural resource sites and their environmental settings have been found to be important attributes in overall vulnerability to theft and defacement in the southwestern United States (Downer in press; Nickens et al. 1981). Examples of variables of this type which have been utilized to analyze vulnerability are the following:

1. Site density, usually quantified as the number of sites per square mile or square kilometer.

2. Site visibility, in terms of the obviousness of physical features.

3. Site type, such as a village site with remains of houses versus a quarry and tool manufacturing site where only stone artifacts are present.

4. Types of artifacts present, for example, sites with decorated and undecorated pottery as opposed to those with only undecorated ceramics.

5. Types of features present, including items such as houses, storage facilities, ceremonial structures, and graves or burials.

6. Site accessibility, for example, distance to trails, roads, private property, and towns.

An analysis of vulnerability in relation to site characteristics such as these will be based on information on the condition of known sites in terms of the extent and nature of theft and defacement. Relevant categories of baseline information include the following:

1. Sites recorded as being disturbed by theft, defacement, or both.

2. Sites recorded as being undisturbed by these activities.

3. Sites which are in an unknown condition because information on theft and defacement was not recorded or is unclear or problematic.

4. The extent of theft, defacement, or both at disturbed sites, if quantified.

5. The type of theft or defacement activities evident, if specified.

The analysis must measure the degree of association between potentially significant site characteristics and site condition variables for those sites for which usable information is available. Site characteristics which are found to be strongly associated, either positively or negatively, with disturbance from theft or defacement will become important criteria in the framework for site protection. Continuing analysis of newly obtained site information can be used to further evaluate known associations and to measure relationships to variables not previously identified as significant.

The site data base for an analysis of this type may be derived from several sources. The computerized inventory for sites recorded on National Forest lands in the Southwestern Region is probably capable of providing much usable information. In addition, each Forest's physical inventory of site forms may contain additional relevant data not entered in the computerized system. All newly recorded sites in the Region also can be included in the data base as information on them becomes available. Finally, as the opportunity arises, previously recorded sites will need to be periodically reinspected to

document disturbance from theft or defacement not properly recorded initially, as well as any new damage from these activities. Eventually, sites recorded on other Federal lands in the Southwest also may become part of the data base.

Value Differences Toward Cultural Resources Management

Knowledge is needed that identifies agreements and disagreements in perceptions, values, and behaviors between users, nonusers, and managers toward cultural resources. The problem of value conflicts and lack of consensus is an important one and must involve the Forest user, nonuser, and Southwest cultural groups such as Native Americans (see the paper on Native Americans elsewhere in this volume). The nonuser is identified as a Southwest resident who does not use the Forests, but who may nonetheless value the preservation of cultural resources. Also, it is important to note that Southwest cultural resources have national significance and a sample of nonusers nationally may be necessary.

Protection issues are important, and the management and protection of cultural resources requires knowledge and understanding of behaviors, values, and perceptions. Most management and research have focused on single components such as discussions about archeological laws, the criminal justice system, or the network of commercial collecting. These evaluations and discussions are needed, but most of the problems in resource management are found in the areas of conflict -- or overlap (Clark et al. 1985). We know least about where the conflicts interact.

The rationale for this research is to develop new information that identifies areas of conflict in perceptions, values, and behaviors. The protection framework is based on an understanding of these conflicts and resolutions. The relative value of cultural resources emerges from the contexts of the various managers and cultural groups contacted. This information is analyzed for interrelationships and emerging factors are weighed for the predictive framework. For instance, the Federal land manager's responsibility in many agencies is to manage for multiple use; these managers are the designated stewards of our cultural heritage. The archeologist looks at cultural resources as a professional relationship. Law enforcement officers look at the enforcement of archeological laws as a professional duty but frequently have real conflicts with other enforcement priorities. The commercial collectors see looting as their legitimate right, while other types of collectors have similar rationales. The Native American looks at cultural resources with religious and spiritual values while wildlife organizations see cultural resources as secondary to wildlife values. Moreover, economic values of energy, industry, and land development often take precedence over preservation values. Congruence and lack of congruence between values are to be identified in order to develop guidelines for protection.

Information needed from managers (across Districts, Forests, and Regions), users, and nonusers includes:

1. The relative importance of cultural resource values versus other resource values (for instance, timber, range, recreation, wildlife, and water).

2. The perceived seriousness of the extent of theft and defacement.

3. Attitudes about selected management practices. For instance, an assessment needs to be made of the relative acceptability of selected practices or treatments in known cultural resource areas. These practices include:

   a. timber cutting
   b. fuelwood cutting
   c. grazing
   d. recreation uses
   e. chaining treatments
   g. water control devices
   h. range improvement
   i. stock tanks
   j. road construction
   k. oil and gas operation
   l. controlled burns
   m. wildland fire

4. The perceived effectiveness of protection strategies such as retrieving artifacts, offender sentencing by the courts, law enforcement efforts, and interpretation and education efforts to instill values about cultural resources.

One data collection approach is self-administered questionnaires given to randomly selected managers, users, and nonusers. Preliminary to this, it is suggested that exploratory, informal conversations be made with users and managers; this effort will identify key issues.

Motivations for Theft and Defacement

Causal factors need to be identified that explain why people conform or commit theft and defacement behaviors. The benefit of knowing why an individual or group comes to act illegally allows researchers and managers to develop and test prevention and control strategies for targeted groups. Motivation research also allows for the development of a profile of people (in conjunction with research on site vulnerability). Types of people potentially profiled include: (1) the commercial collector; (2) the intentional collector who loots for personal interest and possible material reward; (3) the recreational collector; and (4) the complier or person who is committed to the law and preservation values (Christensen in press). Theories from several disciplines have been offered to explain illegal behavior (Christensen 1978; Wilson and Herrnstein 1985), as have typologies of such behavior (Cohen 1973; Gramann et al. in press; Wade 1967). None of these perspectives has been tested with regard to theft and defacement of cultural resources. Some

typologies are based on acts (behaviors), actors (people), or motivations or reasons for action. A suggested approach to this research issue is to provide a rationale for the acceptance or rejection of previous typologies and develop revised or new paradigms relative to cultural resources. Possible respondents include violators, where participation is on a volunteer basis and information is treated confidentially. Oftentimes, violators are willing to respond to personal interviews or self-administered questionnaires and provide researchers and managers with valuable information. New information about perceptions of users and nonusers regarding the types of people who commit destructive behavior is also valuable. New knowledge about cause will be integrated with other factors in the development of a protection framework.

Site Protection Strategies

There are a number of protection strategies in use or potentially utilizable to prevent and control theft and defacement at cultural resource sites both on National Forest lands in the Southwestern Region and on other Federal lands in the Southwest. General categories of techniques now in use with some specific examples of each are listed:

1. Site Intervention

   a. Signing[6] (Dustin 1985; Johnson and Swearingen in press)
   b. Fencing
   c. Access control
   d. Anti-intrusion devices (including remote cameras)
   e. Less obvious project-related marking of sites
   f. Restoration or complete excavation of damaged sites

2. Public Involvement

   a. Prosocial behavior such as reporting violations by the public (Christensen and Clark 1983)
   b. Volunteer programs such as adopt-a-site and site stewardship (Pilles in press)
   c. Community programs (Pilles in press)

3. Public Education and Interpretation (Alderson et al. 1976; Sharpe 1976; Tilden 1957)

   a. On-site programs
   b. Outreach programs
   c. Volunteer excavations
   d. Media relations (including press coverage of successful law enforcement cases and undercover operations)
   e. Behavior modification programs (Gramann and Vander Stoep 1986)

4. Regulatory Controls

   a. Written orders and closures
   b. Action plan implementation
   c. Directing use through trail and road location
   d. Policy and regulation development
   e. Permittee compliance

5. Law Enforcement

   a. Investigations, citations, and arrests
   b. Informants
   c. Rewards
   d. Patrol techniques
   e. Specialized training

6. Legal Controls

   a. Alternative sentencing
   b. Selective acceptance of cases
   c. Court-imposed penalties
   d. Administrative settlements
   e. Forfeiture

7. Other Management Strategies

   a. Inter-agency communication and cooperation
   b. Action planning
   c. Modification of existing laws and regulations

At present, there is no general evaluation of the conditions under which each of these protection strategies will prevent or control theft and defacement at cultural resource sites in the Southwest. Analysis of their relative effectiveness will produce criteria which Federal land managers can apply to select the appropriate strategy or strategies to protect a site once its vulnerability and priority for protection are known.

SUMMARY AND CONCLUSIONS

The protection of cultural resource sites is a serious problem on National Forests and other Federal lands in the Southwest. Sites are being disturbed by theft and defacement at an alarming rate, and the majority are totally unprotected. Unfortunately, it is not possible to protect all currently known sites and the problem will increase in magnitude in the future as more sites are discovered. Faced with this situation, Federal land managers are asking which sites should receive priority for protection, and how most effectively to prevent or control theft and defacement at those sites. The research proposed here focuses on four factors in cultural resource protection: site characteristics, value differences toward cultural

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[6] Christensen Harriet H. and Daniel L. Dustin. 1986. "Reaching recreationists at different levels of human development: a review of Kohlberg and Gilligan," presented at the First National Symposium on Social Science in Resource Management, Corvallis, Oregon, May 12-16.

resource management, motivations for theft and defacement, and effective site-protection strategies. All of these must be analyzed to answer the questions managers are asking. The goal of this research is provide managers with a protection framework to assess site vulnerability, prioritize sites for protection, and select effective protection strategies. There is a critical need for this research in order to provide a sound basis for making difficult cultural resource protection decisions now and in the future.

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The Handwriting on the Wall: Prospective Preservation Research Strategies for the U.S. Forest Service[1]

Larry V. Nordby[2], Michael R. Taylor[3], and Judith G. Propper[4]

PHILOSOPHY AND ORIENTATION

Many papers at this symposium have emphasized that the Southwest contains what is probably the nation's richest, best preserved, and most complete record of human prehistory and history. This can be attributed not only to the density and diversity of cultural remains, but also to the fact that the Southwestern climate and environment have affected these remains less harshly than in most other parts of the country. To say that these resources are remarkably well-preserved, however, is not to imply they are unchanged or that they will last forever. Many cultural resources have been damaged or destroyed over the centuries by the natural forces of erosion and deterioration, as well as by human impacts; these processes continue. Because the record of the past is finite and non-renewable, such losses diminish our chances to study, understand, and interpret potentially critical parts of the story of past cultures.

Consequently, a program to stabilize, repair, and maintain the architectural residues from archeological and historic sites is an essential component of a proactive cultural resource management framework. The goals of such a program are to:

1. minimize the loss of important scientific information;

2. preserve for future generations examples of past technologies; and

3. enhance the interpretation and appreciation of past cultures by preserving places that convey a sense of past lifeways and the people who lived there.

Such a program must seek to preserve the scientific and heritage values inherent in the original construction materials or "fabric," rather than focusing simply on manipulating or altering the fabric to prevent or inhibit further deterioration, a principle that is reflected in several recent preservation trends. One is the movement toward "softer" stabilization materials and a shorter-term maintenance cycle in order to maintain site integrity. Another is a preference for methods such as backfilling and drainage control, that preserve resource integrity without manipulating original architectural fabric. Increased emphasis on the role of careful, often intensive architectural documentation as a prelude to stabilization fabric work also reflects this attempt to preserve the attributes and values of architecture.

With over 20,000 cultural resources currently inventoried in the Southwestern Region, it clearly is not feasible to preserve or stabilize every property using traditional methods. National Forest managers are faced with difficult decisions about which sites to preserve using limited financial resources. At the present time, those decisions are being made on a highly subjective and opportunistic basis, in the absence of knowledge about the most critical stabilization needs, and outside of a programmatic framework.

The overriding preservation research need is to assess the status of the Region's cultural resources. Since archeological survey is generally the method used first to acquire information about sites, it is imperative that preservation information be obtained when surveys are undertaken. In such cases, data gathering on site condition, the nature and scope of deterioration, and how much standing architecture remains must be viewed as an important objective of the work. In tandem with the need to include preservation data during ongoing and future surveys, there is also a need to evaluate the quality of whatever preservation data already exist from past surveys. During assessment and evaluation, questions to be kept in mind include:

1. How many sites in the Region have architecture standing above grade, and how much of it is there at each site?

2. What is the condition of each site in the

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[1] Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2] Larry V. Nordby is Chief of the Branch of Cultural Research, National Park Service, Southwest Cultural Resources Center, Santa Fe, NM.

[3] Michael R. Taylor is an archeologist and preservation specialist with the Museum of New Mexico, New Mexico State Monuments, Santa Fe.

[4] Judith G. Propper is the Regional Archeologist of the USDA Forest Service, Southwestern Region, Albuquerque, NM.

Region, especially those with standing architecture?

3. Can resources be grouped into classes for preservation purposes? Which classes are in the greatest and most imminent danger?

4. What are the major sources of fabric deterioration and value loss?

5. How can we determine which sites should receive highest priority for stabilization work? What level of documentation is appropriate for sites where stabilization is inappropriate or unlikely?

Preservation data-acquisition using redesigned survey forms and upgraded site files is a critical first step in determining stabilization needs. This knowledge can be used to guide the development of carefully designed, specific research projects that ultimately will assist program managers and professional cultural resource specialists and technicians in making wise decisions. Three such research projects are listed in the following sections.

These projects focus on three lines of inquiry, all of which are necessary to preserve values inherent in historic and archeological architecture.

1. What must we understand about the fabric we want to preserve? This question subsumes studies about the physical and chemical properties of original materials, as well as potential stabilizing products.

2. What is the effectiveness of current techniques available to address critical stabilization problems? What new and more efficient techniques can be used to meet stabilization problems?

3. What construction techniques were used in the past? How can this knowledge aid in understanding and preserving the technologies and cultural values embodied in the sites we are trying to preserve?

Each of these areas is described as a project in the following discussion; however, each project is presented as a series of linked modules, each synonymous with a subproject. Modules are subdivided into phases, and normally each phase is roughly equivalent to a year's research work. Phases may be rearticulated either between modules or within a single module to form a single stage of the research project. This provides multiple-year continuity and also an intellectual link throughout any single research module. Furthermore, each phase for each module becomes a funding request unit or building block from which the overall project is built, as shown in figure 1.

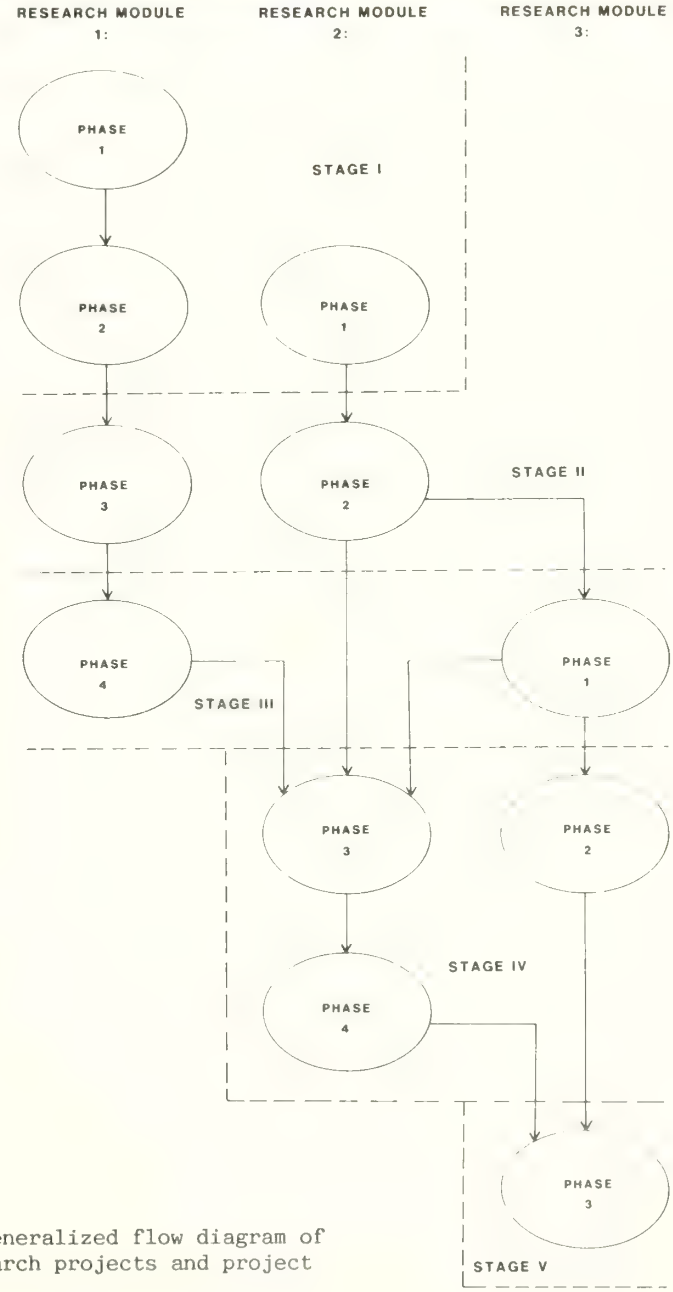
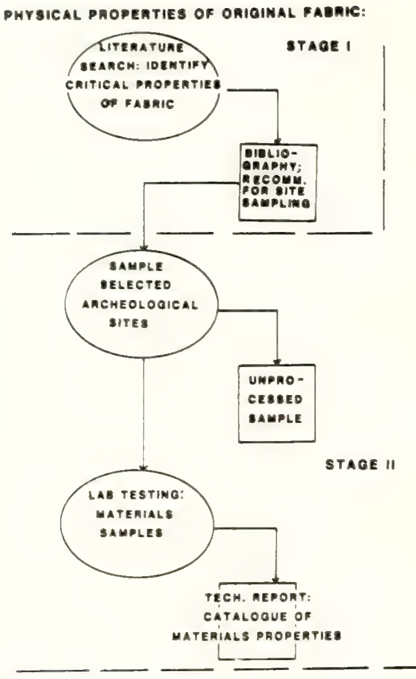
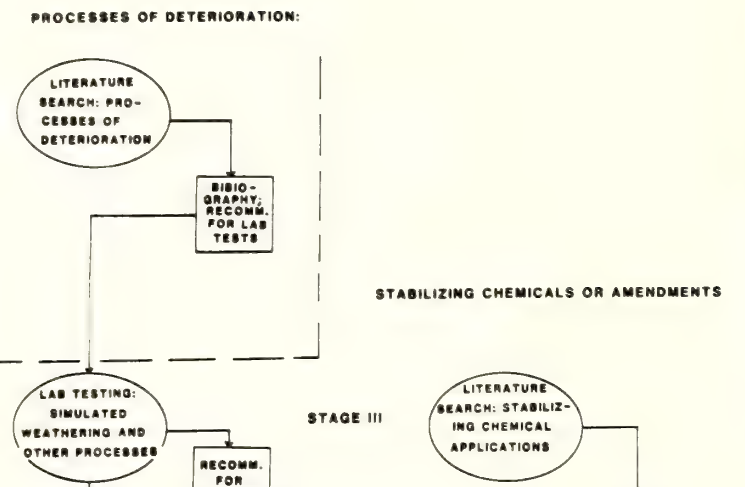


Figure 1.--Schematic generalized flow diagram of preservation research projects and project nomenclature.





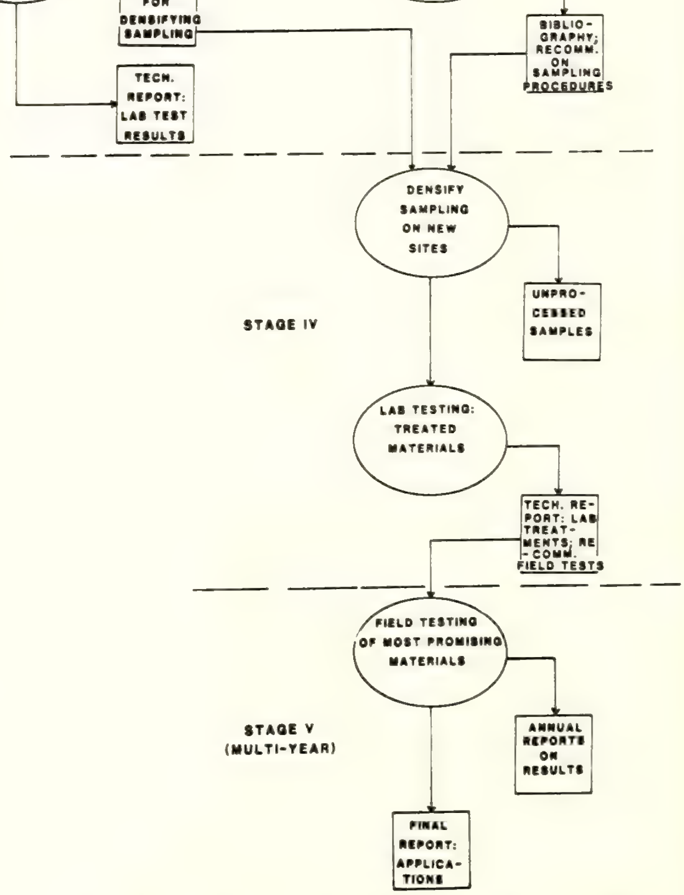


Figure 2.--Flow diagram of fabric and materials studies research project, composed of three research modules.

FABRIC AND MATERIALS STUDIES

The Need

The primary objective for this research project is to understand better the materials or original "fabric" of which archeological ruins and historical buildings were made. Generally, these components include stone, mud or adobe, and wood. Knowing the properties of the structural components will ultimately help to identify what stabilizing chemicals can be used to retard natural processes and negative cultural impacts. This is an extremely complex process, since each site within each National Forest can be expected to be idiosyncratically constructed from materials having diverse properties, and each site probably faces a number of environmental and erosional conditions. Although some of the factors have been considered in several sources (Clifton and Davis 1979; Torraca 1982; Smith 1982), the physical and chemical properties of Forest Service sites have never been identified as part of a programmatic study, whether descriptive or evaluative in nature. Nor have environmental factors been systematically described, evaluated, and applied to predictions useful for prioritizing stabilization targets. Understanding the interplay between fabric and process should precede evaluations of potential products for stabilization use.

Potential Project Orientation and Execution Strategies

This project is extremely complex, and is divided into the three modules shown in figure 2. The complex and interdependent nature of these studies requires that some project phases from different modules run concurrently as project

stages, but the general trend in module priority and organization is (1) determining the physical/chemical properties of original fabric; (2) research into the process of deterioration; and (3) a search for stabilizing materials. Outputs from various research phases are also shown as rectangles in the figure, with the phases themselves shown as ovals.

As is shown in figure 2, the first phase in each research module is a comprehensive literature search conducted in order to ascertain to what extent the topic has been dealt with previously by other agencies or organizations. Bibliographic searches can be done using a computer link that can access any building material conservation title in the extensive libraries of leading architectural conservation centers, such as the Getty Conservation Institute in California, the Association for Preservation Technology in Canada, and the International Centre for the Study of Preservation and the Restoration of Cultural Property in Rome. On the regional level, reports generated by the National Park Service, other federal, state, and local agencies, as well as institutions and individuals, constitute valuable sources. This literature search should be augmented by consultations with organizations currently studying the issue, in order to insure that (1) no research is being replicated; (2) there is maximal cross-fertilization between researchers and (3) gaps in the research are identified. The output for each literature search is a bibliography coupled with a set of recommendations that focus on sampling or laboratory testing procedures.

Returning to the modules, the first one activated should be research into the physical and chemical properties of original fabric: wood, stone, and adobe or earth. A number of studies that could be termed generic have already been done on this topic (Clifton and Brown 1978; Clifton and Davis 1979; Fenn and Chambers 1978; Torraca 1982). The interim objectives for such work have been to apply standard strength, porosity, and other tests developed for modern buildings, or to explore the ways that soil chemistry and such factors as particle size, clay mineralogy, and sand grain shape affect longevity. Nevertheless, the ultimate hope remains that better preservation will result from a broad spectrum of sample testing, in part because better knowledge of building material composition will aid in selecting soils that will produce more durable preservation mortars or bricks.

In terms of contributing to studies on sites of the Southwest, Forest Service properties have contributed little to data compilation, even though generic studies have some application to the Forest Service preservation effort. Identifying the physico-chemical properties of building materials will require laboratory study, processing, analysis and testing of samples collected in the field. If archeological work involves the exposure of walls with original fabric, samples should be collected and analyzed to create a catalogue of the physico-chemical attributes of both prehistoric and historic sites, not to mention fabric conservation (Price 1984). Supplemental strategies include sample collection from sites having standing walls as they are documented during survey, or revisitation of sites already in the data base with the same objective. In any event, sampling of the materials from sites will probably require some assessment of the scope and intensity of the sampling. Examination of the fabric of nineteenth century Euroamerican sites such as log cabins or board-and-batten buildings should also be included.

Once collected, specimens must be sent to a laboratory where a portion can be destructively analyzed, with the remainder preserved. Acquiring laboratory services is a common requirement for all three research modules, and requires a management decision as to how best to have data processed and analyzed. Since this is a complex issue, we'll return to it after discussing all three modules.

The outputs from this module are of several kinds. First are the preserved portions of samples from archeological sites, which can be used for future study or reference. The other two products are the catalogue of attributes, probably retained for in-house use by Forest Service preservationists, and some type of publication generated for the preservation community at large, as the reports of other agencies have been in the past. Information on the physico-chemical properties of building materials is then used to design the laboratory testing program for studying the processes of deterioration, the second research module in this project.

As with the first module, the second begins with a literature search into the processes of deterioration, which can be broken into two classes: natural processes, and impacts due to various human forces. The research program described in this module seeks to isolate the many variables of natural erosion, treating human factors separately. In reality, variables of both classes are inevitably interdependent, contributing to extreme project complexity.

Natural processes are numerous, and an exhaustive listing is not possible in a paper of this length. Abiotic processes are ongoing and constant, including moisture, wind erosion, and thermal shock caused by solar exposure, among others. Biotic processes relate to floral- and faunalturbations and negative architectural impacts.

For most sites, moisture is the main erosive culprit, but it arrives in many forms and stays active long after a passing thundershower deposits it. Examples of moisture-related problems include precipitation in the form of rain or snow, rising damp or capillary action from moisture entering at wall bases, and condensation within wall voids, material pores, and inside roofed structures. A compounding factor is differential soil loading,

which permits lateral groundwater movement, especially a difficulty when soluble salts are deposited on wall faces as the water evaporates. In some areas, freeze-thaw cycles accentuate the erosive condition.

The effects of wind and wind-born particles on historic structures is an area that has never been adequately examined by any study, although it is believed that abrasion from wind-driven sands can lead to the eventual failure of building systems under certain environmental conditions. Windbreaks comprised of native grasses or larger vegetation, and manufactured windscreens, have been recommended to reduce abrasion, but without supporting evidence.

Solar exposure, wall orientation, and consequent differential thermal expansion or contraction all detrimentally impact historic structures. Perhaps the most deleterious effect is from snow accumulation along the north side of a wall, where the freeze-thaw cycle is free to act using the natural expansion of ice. South wall faces comprised of paint and exposed wood change in appearance because of color changes induced by ultraviolet light, as well as from oxidation. Thermal shock occurs when a building's various components are suddenly and differentially heated by the sun because of the presence of shade trees.

Destructive biotic processes also relate to trees, wherein mechanical wall deformation follows the development of root networks. Because moisture retention is often better in locations where wall rocks shade the ground, trees may tend to grow along wall alignments. Once established, these trees drop organic material that effectively mulches the soil and accelerates the growth rate as well as root penetration. By-products of plant activity include the disturbance of stratigraphy and archeological deposits, and the disruption of surface runoff patterns. Chemical changes of original fabric from root proximity have not been examined.

Closely linked to floral impacts are those stemming from natural fauna. The most nefarious creatures are burrowing rodents, many of which enjoy the soft soils and high organic content of archeological sites. Dry rock shelters, overhangs, and caves containing ruins are safe from most moisture-related impacts, yet are often riddled with burrows and dens. Standing walls are often covered with rodent droppings, the chemicals of which may be corrosive, and plasters, mortars, and wooden elements are often destroyed by gnawing or digging. Insect or bird damage occurs on a less universal basis, but the scope of these impacts and ways of controlling fauna have not been thoroughly examined.

As if the litany of natural processes was not enough to complicate the research program, a second class of potential crises is paradoxically introduced by attempts to study and manage the resources and make them accessible to the public. Of these, increased visitation poses a set of problems that must be addressed. Visitors climbing on the walls, or simply walking through the site and developing pathways that alter drainage across it, are one source of damage. Differential loading is common for sites that are interpreted to the public. These problems have not been studied, nor have "visitations" by livestock which rub against standing buildings.

Research conducted as part of this module should also identify the potential deleterious effects of such actions as timbering, helicopter flights, blasting, and fire suppression. Each of these activities might produce vibrations that affect standing architecture, by rapidly alternating tensile and compressive stresses. The most susceptible elements are loose plasters, cracked masonry, and rubble cored walls. One study that the National Park Service conducted at Chaco Culture National Historical Park examined the effect of heavy trucks hauling road building materials near the ruins of Chacoan Great Houses (King and Algermissen 1985). The study concluded that sympathetic vibrations with negative impacts on the ruins resulted from the truck traffic, especially if located closer to the ruin walls, but also found that "detuning" walls was possible, using temporary emplacements that linked the wall with the ground. The application of this method to the timbering industry, especially for Euroamerican structures present in higher elevations, should be explored.

Fire, fire management, and fire suppression include dropping chemical suppressants from airplanes, controlled burns, water applications, and building fire lines. What are the impacts on historic structures? Clearly, wooden structures and elements such as beams in prehistoric ruins would be destroyed if fires occur. Cracking and spalling of stone and adobe elements are also likely. What temperature level is acceptable? Fire suppression activities have been described by the National Park Service's assessment of the La Mesa Fire at Bandelier National Monument (Traylor 1984), but no assessment of chemical alteration of masonry is included.

We have spent considerable ink describing some of the many things to consider as part of a program that studies deterioration, and these variables have been presented as subject matter for a comprehensive literature search. The output from the search should be a bibliography of sources, followed by a report containing recommendations for laboratory tests geared towards solving natural impact problems and for monitoring field situations generally related to human impacts.

The next phase in this module entails laboratory testing involving simulated and accelerated weathering processes, once again a laboratory procedure. An ancillary process is the gathering of statistics regarding visitor use or vehicular vibrations, probably by establishing monitoring stations in the field. Both phases would produce reports which link deteriorative

processes with the physico-chemical properties of materials to produce a sophisticated understanding of what is needed in preservation research, while setting the stage for the final module: the search for stabilizing chemicals or amendments.

In the recent past, a number of tests have been conducted on the viability of using chemicals to consolidate and retard the erosional rates of building materials such as stone, adobe, and wood. A few materials have proven positive, but most have not. Application of the proper stabilizer is dictated by original material, interpretive needs, significance of the property, the specifics of natural erosional processes, and cost. Most are considered in various studies that relate laboratory testing results, such as Sleater (1977). This kind of study constitutes the fodder for the literature search that initiates this module. The output for the first phase of this module is a bibliography of research into stabilization chemicals and a set of recommendations for ensuring that all structures needing stabilization help through amendments are considered, especially in light of the variable sets addressed by the first two modules.

No two sites are alike in material components and no two share identical environments. Sample densification may require prioritization or grouping of the most similar sites. What works as an amendment at one site may prove disastrous at another location. For example, one of the most successful chemical amendments is Rhoplex, generally part of the liquid component of a mud mix. A site that receives 8 inches of rainfall per year and has 160 frost-free days may require a Rhoplex-to-water ratio of 1:7, whereas a site receiving 14 inches of rainfall and only 100 frost-free days may require more of the chemical. Furthermore, some sites may require more than one mix for optimal performance in their different parts.

Selection of chemicals for laboratory testing proceeds from the literature search. These potential amendments are then subjected to various tests to screen out those that simply do not perform well. The products that survive the laboratory testing can then be run through a field testing routine that rearticulates all data from all modules. Specific field sites should be selected to monitor the effects of various destructive agents noted previously. Either existing sites or specially constructed ones can be used; however, it is recommended that at this point in the program a series of test walls, using a wide range of materials and amendments, be constructed at various locations in the Region where natural and human impacts occur.

The utility of such a program has already been demonstrated by several studies. For example, in an attempt to determine which chemical amendments to adobe mortar would be effective in retarding the cyclical maintenance needs of stone masonry walls required at Chaco Culture National Historical Park, the National Park Service developed a comprehensive field research project. It began in the 1970s and is still operational, with reporting ongoing. Positive results from this project have already been implemented at the Monument.

A more specific example of such research is the adobe test wall project at Fort Selden State Monument in southern New Mexico (Taylor 1988). The exposed historic adobe walls at the site are in constant need of maintenance. New Mexico State Monuments, Museum of New Mexico, embarked on a project in which 20 adobe test walls were built to experiment with chemically amended mortars and sprays, various foundation treatments to deter capillary rise, and capping techniques used to protect the tops of adobe walls. In 1987, the Getty Conservation Institute joined the adobe research at Fort Selden by constructing 30 new test walls in which various chemical infiltrations, shelter designs, drainage systems, backfilling techniques, and structural reinforcement systems are being tested (Agnew 1987). This cooperative effort between government and private non-profit concerns is the type of research needed to be cost beneficial for agencies such as the U.S. Forest Service. The Institute will have provided $180,000 in funds and matching contributions by the end of June 1989 to the Fort Selden research effort.

Project Products

It is important that the field testing program runs for several years. Often, secondary problems with chemical amendments occur later in the exposure cycle. One suitable example is color change following long-term exposure to ultraviolet light. Thus, the field testing program should generate a report for each year that it lasts. The ultimate output is a final report that identifies the best stabilizing amendments and matches them compatibly with original fabric and site-specific environments.

The basic organization for each module in this project is literature search, followed by laboratory testing or field monitoring, and field testing. As noted earlier, a major need is the acquisition of laboratory services for studying fabric, weathering processes, and stabilization materials. Establishing an architectural materials laboratory or contracting for services with an existing laboratory is essential to the success of this research program. It must deal with wood, adobe, and stone, and should handle plasters and paints as well. The lab should provide particle size analysis, mortar analysis, paint scheme reconstructions, and porosity tests (Teutonico 1987). A small architectural preservation laboratory could be set up for as little as $15,000, and providing the services in-house would ensure continuity, standardization, and responsiveness. Contracting for services may save costs but might inhibit testing continuity between modules.

RESEARCH INTO ALTERNATIVE PRESERVATION STRATEGIES

The Need

The integrity of the cultural resource base is crucial to maintaining the values represented in the masonry of individual ruins and in historic buildings of stone or wood, whether exposed by natural, archeological, or other processes. Stewardship of such sites implies that one is able to make informed decisions about the ways that this integrity will be best preserved by selecting from a list of preservation options. These alternative classes of strategies normally include: (1) direct fabric alteration methods such as repointing, resetting loose stones, filling embrasures with masonry, or capping the walls with more durable materials; (2) changing fabric environments through backfilling, constructing shelters, or attempting to control water movements by installing drainage systems; and (3) value preservation only through documentation.

Forest Service employees charged with preservation responsibilities must make decisions not only between strategy classes, but also within each class. Although there is literature describing the ways to shape and set stone in stabilization, the options stop short of preserving values, and often focus on the most expedient and efficient way to get the job done without much focus on replicating ancient or historical craftsmanship. There are no analytical or engineering studies on backfilling methods as they might be applied to archeological sites, and drainage system designs are based on nothing more than the intuitive feeling that water normally flows downward and assumes the path of least resistance. Documentation is a still evolving process, yet when to apply it in place of other classes of strategies, and what medium to use (photography, video-tape, or narrative/checklisted data, etc.) remain decisions that are made without a programmatic objective. A short exploratory foray into each class of strategies will help place this project into its proper context.

Potential Project Orientation and Execution Strategies

The techniques of Native American or pre-industrial Euroamerican building traditions encompass the range of individual actions that are appropriate for use during stabilization projects. Once materials that approximate the original ones as closely as possible given other managerial constraints are selected, they must be applied in such a way that surface finish and other attributes are compatible visually and in other ways with the original fabric. Such techniques as dry packing, dampproofing, surface tooling, newlaying, re-tempering, and controlled curing not only comprise the newly emerging lexicon of specialized stabilization terminology (Metzger, Eininger, and Gaunt 1988), but form the link between any material and the technical demands of installing it. The cost-benefit factors that accompany each technique are poorly understood, so the parameters that establish maximal material durability remain a mystery. Questions such as whether in any given case "newlaying" or "relaying" is more cost-effective or value-preserving remain unanswered.

As shown in figure 3, one research framework that attacks this problem identifies the complete spectrum of stabilization activities by reviewing stabilization reports and consulting stabilization personnel. Each action in this broad base must then be tested either using laboratory modeling or field testing. The field testing component is extremely important, and must be complex enough to examine various unamended mortars, soil-based mortars amended with a cross-section of chemical preservatives, and various soil-cement admixtures. Ideally, masonry styles involving various rock orientations and the viability and durability of wall caps should also be examined. Throughout the field tests, careful monitoring of material costs and time needed to use each technique are essential, so that the critical variables in executing a cost-conscious job that also preserves cultural values can be isolated.

A second component of this project consists of changing the environment of the fabric, generally through some form of terrain modification. For example, backfilling newly excavated ruins has been used for decades as a standard, intuitive preservation strategy, conducted almost as an afterthought to archeological field work. As stabilization budgets have diminished, its importance as a technique without any apparent future investment has grown. A traditional application was simply to recruit as large a labor force as possible using promises of liquid refreshment, pass out the shovels, position the recruits around the hole and shovel all the dirt that had been removed in the interests of science back into its place of origin in a cloud of sweat and dust. True sophistication was shown if some type of liner, such as polyethylene sheeting, was installed as a prelude to these energetic antics.

Since such liners may inhibit the exodus of moisture from site features under certain conditions, other materials have been introduced. These include filter fabrics and liners made of space-age materials; however, no data are available on which is best under any given set of circumstances. Another approach has been to line excavation floors with bentonitic clays or specially colored sands, either to demarcate maximum excavation depth or to control moisture movement. There are no quantifiable data to suggest that any of these techniques has positive, negative, or neutral impacts on preserving buried archeological features.

Finally, there is the question of composition of the backfill materials and the technique by which the feature is filled. Is the same material that came out of the excavation unit the best possible selection for replacement, or should

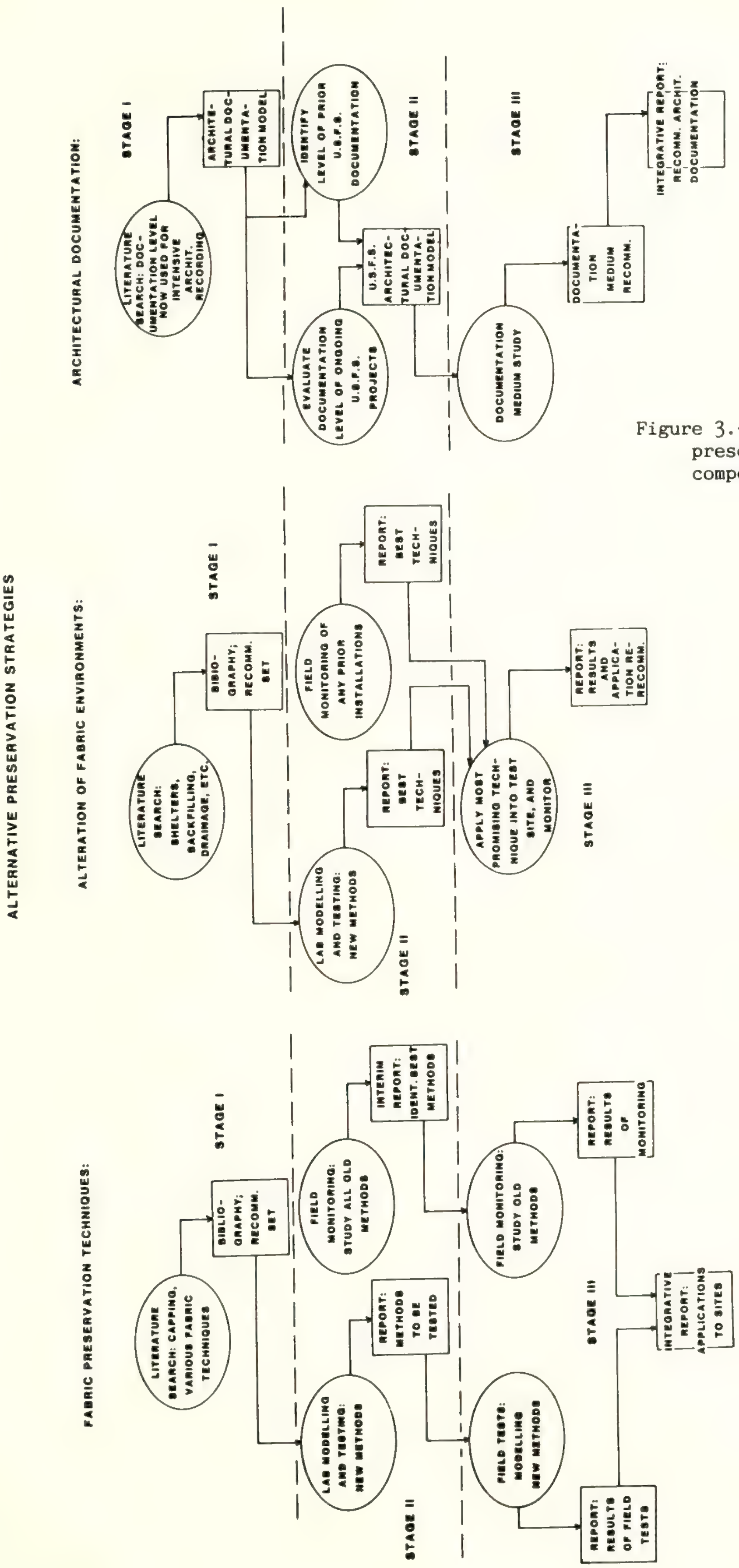


Figure 3.--Flow diagram of alternative preservation strategies research project, composed of three research modules.

materials with higher porosity and permeability such as sand or gravel be used? Would highly expansive clays be preferable? Regarding selecting a backfilling technique, the options generally either entail simple shoveling or compaction of the soil as it is being replaced in layers 10-15 cm. thick, using mechanical or hand-held tamping devices. Once again, no data exist that support either practice, or that indicate the likelihood of wall deformation or collapse under specific conditions.

Selection and design of appropriate drainage systems are issues closely related to backfilling, since installation may be enacted concurrently. Although in the past such devices as dry barrels and orangeburg pipe were installed as solutions to deterioration problems caused by surface water, the vagaries of maintenance programs and the absence of overall systemic design generally led to speedy obsolescence and ultimate abandonment. Nordby (1978, 1979) has installed several drainage systems at Aztec Ruins and Pecos National Monuments, and designed several others (Nordby 1984a, 1984b), yet the efficacy of such systems remains unquantified. Generally, the best system is considered to consist of two parts, a water collection subsystem and a water transport subsystem, functioning together in order to handle both surface and groundwater. No concrete facts support these assertions, however.

Another way of preserving sites through environmental manipulation is the use of shelters designed primarily to mitigate the impacts of precipitation. Of these, probably the best-known southwestern example is at Casa Grande National Monument, and the most recent applications are the Badger House shelters at Mesa Verde National Park. Although engineering and design factors have changed through time, generally shelter use is offered as a panacea for ruins with earthen-walled or adobe construction, when other stabilization methods are believed or demonstrated to be inadequate. Nevertheless, the inadequacy of other methods generally has been based on subjective assessments of adequacy, not of quantified research that takes many environmental and materials variables into consideration. Because the visual impact of a shelter is generally the greatest of any stabilization method and the resultant structure may itself end up competing for maintenance dollars, many observers deplore them.

Finally, the use of cappings has been evaluated by Taylor (1987). Generally of more durable materials than the walls they surmount, cappings almost always affect the appearance of the site. A cap design that encourages runoff and discourages the tread of unauthorized visitors' feet often is visually unappealing. It is important not only to identify the best design from several alternatives, but also to weigh the cap's effectiveness in terms of potential architectural value preservation.

The basic framework for research on this topic is identical to that which was discussed previously: compilation of literature on system designs and backfilling options, and consultation with stabilization practitioners. Engineering firms specializing in this type of work can then model various techniques in the laboratory or conduct field tests where either backfilling or drain installation have been attempted. In some cases, new testing may be warranted in order to control variables from the beginning of the testing program. Selection of sample sites could focus on individual sites or National Forests, and must also consider precipitation patterns. The results of laboratory modeling and field testing should identify the parameters that lead toward informed selection of techniques for modifying site environments.

The final research module in this project seeks answers to questions about architectural documentation, a practice that normally accompanies all stabilization projects. In this case, however, management is compelled by circumstances such as insufficient resource availability to adopt a policy of benign neglect or abandonment of individual walls or sites. This places a site into a salvage mode, where fabric loss is either imminent or will inevitably occur because the site's values are deemed less than those of other sites. Rather than simply allow such sites to degrade without further attention, a procedure must be developed to document selected architectural attributes and annex these records into the Forest Service data base. This is a procedure that does not necessarily entail research beyond that of surveying the literature, investigating alternative documentation strategies, and deciding the level of, and medium for, documentation. Knowledge of when to apply the method should also stem from the study.

Project Products

The component modules of this research must distribute project results as an integral element. This essentially consists of a report that describes the results of fabric alteration, site environment changes, and documentation studies. This kind of report would probably have a limited appeal that centers on the stabilization and preservation audience. It is a technical document that gives application guidance for technicians, preservation project supervisors, and program directors. Nevertheless, the report should have a wide enough distribution to extend beyond in-house practitioners.

RESEARCH INTO SOUTHWESTERN NATIVE AND EUROAMERICAN BUILDING TECHNIQUES

The Need

A programmatic commitment to fabric preservation strategies such as stabilization requires that techniques such as repointing and resetting loose stones at least be compatible with practices traditionally used by vernacular masons of the past. Toward this end, it is essential

that preservation craftspersons confronted with the broad spectrum of masonry styles and construction techniques found at Forest Service sites be conversant with what is known about such practices. Unfortunately, with few exceptions (Hawley 1938; Roys 1936; Dean 1969; Nordby 1980; Morenon 1977; Wilcox and Schenk 1977; Wilcox and Sternberg 1981), Southwesternists have expended neither time nor effort pursuing detailed documentation and interpretation of prehistoric masonry attributes other than wall abutments, electing to focus instead upon the similarly additive technology of ceramic manufacture.

The arrival of Spanish and Anglo populations in the Southwest introduced new kinds of structures while it concurrently altered the forms in which Native American materials were used. The ascendancy of logs, sawn lumber, and adobe bricks as building materials was tied to the use of metal tools and hardware, each contributing distinctive construction or use marks to the material. Novel techniques included wider, more massive walls and buttressing, splayed doorways and windows, and other features related to the use of larger buildings such as missions. Often, such edifices were built by Native American masons, working under Euroamerican direction.

Excluding a scatter of recent architectural studies produced in concert with stabilization documentation efforts (Beal 1986; Caperton 1975), little archeological literature is available to use as a training guide. Other potential sources of information might include courses given at university schools of architecture or the replicative studies that occasionally contribute to the study of prehistoric industries, such as the technology of chipped stone tool production. However, we are not aware of any such opportunity except ones in which vernacular Euroamerican architecture is studied.

Thus, the prospective stabilization project director and his assistants face their projects without any technical guidance beyond that which is derived from the modern-day stonemason armed with steel trowels and rock hammers. Although it might prove inappropriate or even disastrous from the cost-benefit viewpoint to abandon these relative conveniences, a need still exists to understand the behavioral processes by which the primary aboriginal or early Euroamerican building materials of earth, stone, and wood were transformed into dwellings or other architectural forms. We propose architectural research that is behavioral and processual in orientation, and thus contributes to archeology and anthropology, but only as a secondary, fortunate byproduct of a more essential and pragmatic need: to comprehend better the values inherent in previously exposed and newly excavated ruins and to apply this knowledge to an improved training regimen.

Potential Project Orientation

The Southwest is characterized by an often bewildering array of architectural forms. In the Native American tradition alone there are unlined pithouses; structures of vertical slabs; single-stone, double-stone or veneer/rubble-cored masonry; rammed earth, jacal, coursed adobe, mud-ball or turtleback structures; and post-houses, to list a few. Further diversity comes from the myriad of smaller interior features that were dug into or built atop the floor or added to the roofs, walls, or entryways. The range of features and building types expanded dramatically after the arrival of Euroamericans. What is really known about the dynamics of building these features? What were the task groups or organizational units that built walls, rooms, roomblocks, or entire villages? How were building stones quarried, shaped, dressed, set, and plastered?

The answers to these questions can be elicited using a research program that incorporates (1) archeological inferences based on architectural attributes; (2) historical and ethnographic synthesis and analogy; and (3) replicative experiment, among other means (figure 4). Although the rudiments of such research could be carried out within the framework of other site-specific archeological studies, the intensive focus on architectural data suggests that it is likely to fall beyond the normal allocations of time and money, and thus might best be considered as part of a separate architectural research package. The synthesis of available ethnographic data from Native American architectural traditions might begin with classic early architectural studies such as Mindeleff (1891), and proceed to evaluate observations about construction technique and residence patterns made at specific pueblos by such ethnographers as White (1962), Titiev (1944), Bunzel (1932), Beaglehole (1937), and Parsons (1925). Coupled with a program of oral tradition elicited from ethnographic informants, this process might contribute to prehistoric task and residence group recognition in addition to a better understanding of building practices. Although we suspect that there is less ethnographic information within the Euroamerican tradition, the same overall orientation applies, with the focus of the research on historic documentation.

Replicative experiment extends this concept to an analysis of modern craftspersons building domiciliary and other constructs using aboriginal or historical tools and methods. Such a process would provide comparative data on how long it takes to build walls using selected methods such as single stone or veneer/rubble-cored masonry. In turn, the results might contribute to assessments of caloric requirements per cubic feet of wall construction, and ultimately to work force estimates such as the one proposed by Lekson (1984: Appendix B) for Chaco Canyon Great Houses (which itself should be tested).

The architectural research proposed above links archeology, ethnography, and replicative activities, and could adopt any one of several conceptual frameworks. One potentially fruitful avenue might encompass the application of

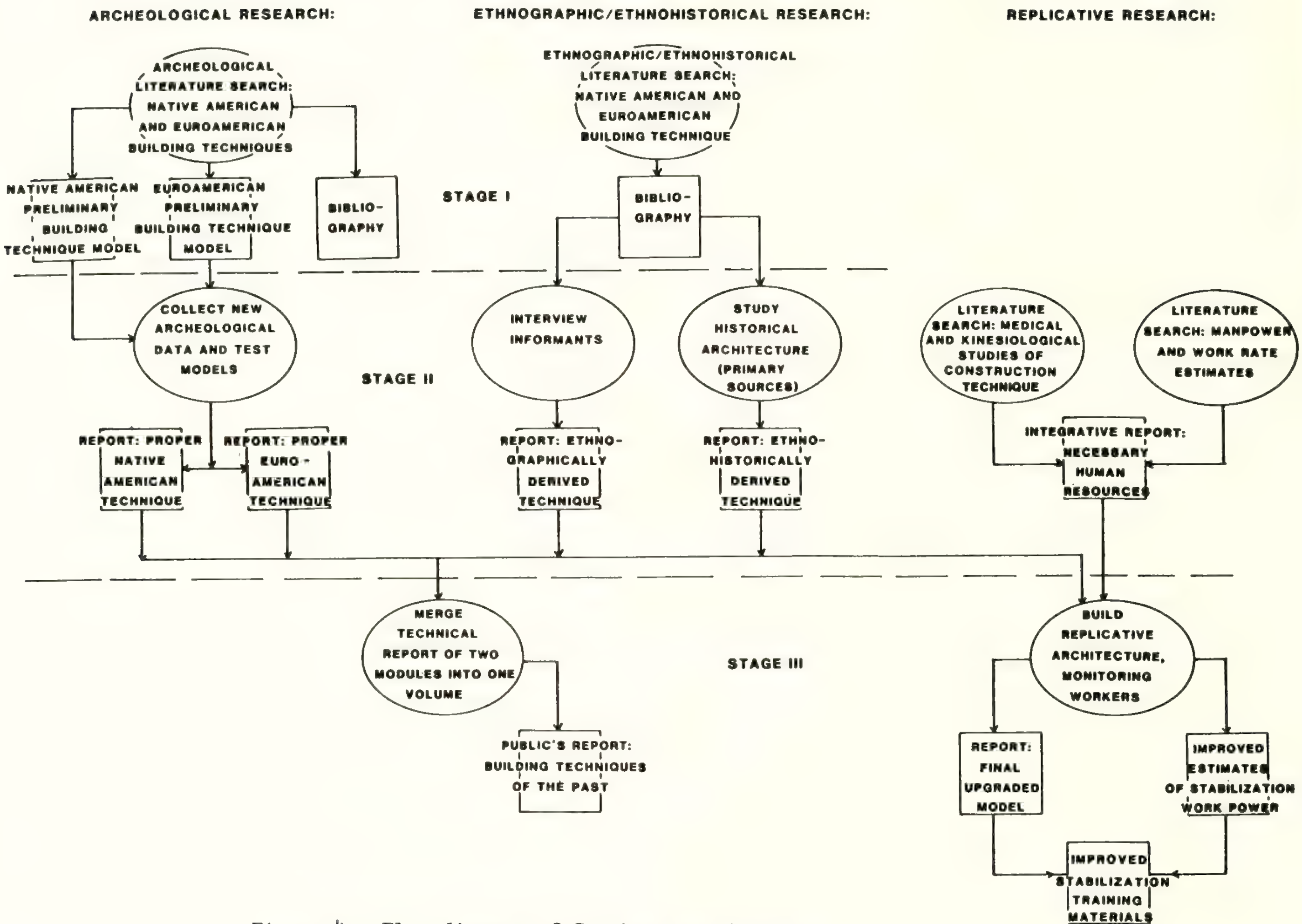


Figure 4.--Flow diagram of Southwestern building techniques research project, composed of three research modules.

Schiffer's (1976) behavioral chain model to Native American construction. Under such a scenario, hypothesized activity segments might include the location, acquisition, and homeward transport of various component materials, alteration of individual stones prior to setting them, post-emplacement modification of wall surfaces, roof construction and floor building stages, the addition of interior features, and periodic maintenance. This method would also create an inferential context for the tool kits, raw material, stockpiles, and byproducts attendant to the industry. Ultimately these factors would result in improved public appreciation of Native American construction-related skills, as well as contribute to preservation of heritage and research values through better trained and more sensitive stabilization personnel. Obviously, the same model could apply equally well to log cabin construction or other examples from the Euroamerican tradition.

Project Products

In order to accomplish this goal, the research just described must generate products that distribute project results to three target groups: the archeological profession, the general public, and stabilizationists or preservationists. An archeological report or suite of reports dealing with each project component is needed as a pure research product that distributes analytical and experimental data; however, it is only an antecedent report. Copies of this report, or of a less technical version, could be marketed in an attempt to influence public attitudes about the heritage and research values that belong to early structures. A professional non-technical writer should prepare any such volume.

Finally, staff charged with the preservation of values through stabilization techniques will benefit from a training program design that

incorporates products from this research. Work force and labor rate data stemming from the replicative experimental component, and sourcing of raw materials that might emanate from ethnographic studies are two immediate and pragmatic applications of project information. Preparation of training materials may require a distillation of the archeological report and the matching of media with the message as part of formal training programs.

CONCLUDING SUMMARY

This paper has urged a transformation in preservation objectives from stabilizing original fabric to the preservation of social and cultural values inherent in that fabric. We have argued that fabric preservation will be a consequential by-product of this approach. The first research step is to assess survey data supplied by both past and current field studies, in order to structure data collection to replace voids in our knowledge. This is an absolutely essential and fundamental step that helps delineate the scope and intensity of research programs that follow.

Three research projects have been proposed in order to address needed preservation research issues, but they are complex. Each project consists of several modules, and ordinarily each module consists of sequential phases. Phases that are carried out simultaneously are a single stage in the research project, and normally each phase has an output or report issued prior to initiating the next stage. This provision builds accountability into the research program, and distributes research findings to interested professionals, preservationists, program managers, and technicians.

Listed in priority order, the three projects are: (1) fabric and materials studies; (2) research into alternative preservation strategies; and (3) Southwestern building techniques. Each also consists of three research modules, providing a total of nine subprojects. Although modules or subprojects could be executed concurrently, if they were carried out sequentially, the order would be:

1. physico-chemical properties of original fabric;

2. processes of deterioration;

3. identifying stabilizing chemicals or amendments;

4. fabric alteration techniques;

5. fabric environment alteration techniques;

6. documentation techniques;

7. archeological and anthropological study of Southwestern architectural techniques;

8. ethnographic and ethnohistoric study of Southwestern architectural techniques; and

9. experimental replication of Southwestern architectural techniques.

Of these, the first six are necessary projects to become proactive in preserving sites with standing walls. The last three represent potentially exciting anthropological research into the values that the prior six strive to preserve.

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Current Issues in Regional Archaeology[1]

Alan P. Sullivan, III[2]

Abstract. -- The current Forest Service approach for characterizing the regional archaeological record is examined. It is concluded that this approach is needlessly exclusionary and, hence, does not facilitate the management of cultural resources on Forest Service land. An alternative approach is discussed -- based on principles of landscape archaeology -- that would satisfy the data requirements of managers and research archaeologists alike.

INTRODUCTION

In evaluating current approaches to archaeological survey and research, Ammerman (1981:82) observed that "There is some irony in the fact that in going back to basics we are likely to discover things about survey archaeology that we may not want to know." Following up on Ammerman's general suspicion, I have the impression that at least one basic problem affects the conduct of Forest Service archaeology. That is, there appear to vacua of knowledge that hinder the management of cultural resources under the jurisdiction of the Forest Service. At the very least, therefore, it would seem reasonable to explore the proposition that management decisions should be based on the results of current archaeological research (e.g., Watson 1985).

Research archaeologists can neither ignore the management responsibilities of the Forest Service nor presume to suggest to the Forest Service what their management responsibilities should be. It is safe to assume, however, that Forest Service management objectives are defined minimally by Executive Order (E.O.) 11593 and criterion (d) of 36CFR60 (Butler 1987). Charged with fulfilling the letter and the spirit of these laws, the Forest Service is necessarily involved with issues that pertain to the production and use of archaeological data.

DATA REQUIREMENTS OF RESEARCH AND MANAGEMENT

It is difficult to envision how anyone could disagree with the notion that the production of reliable information about the regional cultural resource base facilitates both management and research, although the ultimate goals of each may be quite different (Knudson 1985:402-403). From the viewpoint of management, archaeological research should facilitate an evaluation of the significance or "importance" of cultural resources (Northey 1982:66). Moreover, subsequent decisions about the allocation or disposition of cultural resources necessitate that high quality archaeological data be available to guide the decision-making process (Scovill et al. 1977:43; Plog 1981:51).

The amount of common ground, however, is more apparent than real. This is so because of underlying differences in the data requirements of research and of management. Researchers often attempt to understand how different factors affect the characteristics of the data they examine while investigating particular problems (Clarke 1973). Controlling for the effects of different sources of variability often consumes a good deal of research time and effort, especially in the early stages of a project (Daniels 1972). This situation contrasts markedly with the consumption of data for management purposes. The primary goal of managers does not evolve or change because their mission is to ensure compliance with the invariant statutory foundations that define their responsibilities (Holt 1987). It is not surprising, therefore, to find that some archaeologists lodge complaints like the

1 Paper presented at the workshop, Tools to Manage the Past: Research Priorities for Cultural Resources Management in the Southwest, May 2-6, 1988, Grand Canyon, AZ.

2 Alan P. Sullivan III is Research Associate, Laboratory of Traditional Technology, Department of Anthropology, University of Arizona, Tucson.

following: "The proliferation of CRM surveys due to state and federal regulations has resulted in the amassing of information largely regarded by archaeologists to be about as useful as tennis shoes on armadillos" (Church 1988:53). This discontent, I argue, results from fundamental differences in how the interpretive potential of the archaeological record is viewed and how it is to be objectively characterized.

VIEWS OF THE ARCHAEOLOGICAL RECORD

Under the management view of the archaeological record, a cultural resource warrants a site designation only if it discloses a sufficient number of tools, artifact classes, or the proper artifact density characteristics (FSM 2309.4 [1987]). This threshold approach (i.e., either a resource meets or does not meet these criteria -- see especially DeBloois 1983:208-209) has two consequences: (1) some concentrations of artifacts, whose characteristics do not meet the criteria for site designation, are excluded from further management consideration; and (2) potentially meaningful technological information, such as data about the attributes of artifacts that are not discarded in concentrations, is not collected (cf. Thomas 1975). Also, with the management view, detailed descriptions of site variability become extraneous. Although some sites may be targeted for preservation or public interpretation (DeBloois 1983), their management may proceed without a consideration of how and why their characteristics vary, and thus without a consideration of how they may be used to obtain knowledge about the past (e.g., Butler 1987). Clearly, the distinction between sites and phenomena that are not sites is inadequate to cover the known range of material remains that has resulted from different forms of land-use (e.g., Ellis 1978).

These problems do not arise if the regional archaeological record is viewed as the remains of various cultural landscapes (especially Foley 1981). Given the known processes that affect the formation of the regional record (e.g., Schiffer 1987), many archaeologists conceive of it in terms of varying densities of cultural materials across space (Dunnell and Dancey 1983). With this perspective, no judgments need be made about the individual "site" status of varying concentrations of artifacts. Also, non-concentrated artifact clusters are considered as potentially informative sources of data about the technology of land-use and adaptation (e.g., Shott 1986). Hence, description focuses on the technological attributes of land-use rather than on determining whether a resource meets or exceeds a set of threshold criteria.

The landscape view of the archaeological record, however, may be managerially irrelevant because E.O. 11593 and criterion (d)(36CFR60) require the Forest Service to consider only the **clustered** concentrations (e.g., DeBloois 1983). Thus, some evidence about variation in off-settlement sustaining activities, such as resource acquisition and processing (e.g., Binford 1982), may fall through the conservation net. Without these data, it is difficult to see how the researcher or manager can develop an understanding of why different kinds of cultural landscapes arise or, perhaps more importantly, what the variation in the configuration of regional systems means in terms of prehistoric behavior and organization (e.g., Thomas 1985:241).

CHARACTERIZING THE ARCHAEOLOGICAL RECORD: SARG AND THE FOREST SERVICE

The site definition and site characterization procedures of the management view of the archaeological record are similar to those of the Southwestern Anthropological Research Group (SARG 1974). It is well known that SARG research was designed to test hypotheses regarding the locations of sites (Euler and Gumerman 1978:vi). Thus, the SARG research design facilitated Forest Service management objectives because the archaeological site was a convenient clerical unit (see especially Plog 1978:58; also Plog 1981; Fish et al. 1984). It is not surprising, then, that Forest Service characterization procedures focus on determining whether a cultural resource is or is not a site (DeBloois 1983:208).

According to Chapter 10 of the Forest Service's Cultural Resources Handbook (FSH 2309.24 [1987]:10.5--2), a site is a "location of purposeful prehistoric or historic human activity." This is nearly identical to SARG's (1974:110) stipulation that "a site is defined here as any location characterized by the deposition of the remains of human activity." Note that the SARG definition does not entail a concept of purposefulness, and is thereby less exclusionary than the Forest Service's. Some consequences of this subtle difference are explored below.

In the Forest Service system, a cultural resource qualifies for site designation if it discloses one of the following attributes (FSH 2309.24 [1987]:10.5-3):

(a) one or more features (undefined);

(b) one formal tool (undefined) that is associated with other cultural materials, or two or more formal tools;

(c) an occurrence of three or more artifact types (undefined) or raw material types (undefined), or two artifact types or raw material types whose abundance is sufficiently dense that 10 items are found within 100 m^2, or one artifact type or raw material type that is sufficiently abundant that 25 objects occur per 100 m^2.

Assuming that there is intersubjective agreement on what constitutes a feature, a formal tool, or an artifact type, it is unclear how to proceed if the nonassemblage characteristics (e.g., artifact density) of a cultural resource do not approach the threshold criteria (10 or 25 items per 100 m^2). How are they to be treated in terms of the "'yes' or 'no'" decision concerning site status" (S. Plog et al. 1978:385; also DeBloois 1983:212)?

Beyond these problems, the current Forest Service site definition criteria could exclude from management and research isolated occurrences of projectile points (e.g., Rice et al. 1980), ceramic vessels or vessel fragments (e.g., Schroeder 1943), and other artifacts that represent the deposition of key elements of subsistence technologies in locations where they probably had been used or stored (e.g., Simms 1986). These materials represent strong evidence, in many cases, for resource acquisition and processing activities (Oswalt 1976) that SARG was originally designed to investigate (SARG 1974:107), and which SARG would not have been excluded from site status (Jeffrey S. Dean, personal communication).

SARG categorized cultural remains in terms of habitation and non-habitation sites (also called special-use or limited-activity sites), a distinction which some members of SARG acknowledge was next to impossible to maintain consistently (Dean et al. 1978:29). Also, SARG's methods were rather flexible because material remains that were not classifiable as habitation or non-habitation sites could still be recorded as sites even though it could not be concluded that they were the result of so-called "purposeful activity." Thus, by being overly restrictive in its definition of what constitutes a site, the Forest Service reduced its potential management load by excluding a portion of the cultural record.

This situation becomes even more troubling when current Forest Service procedures for characterizing "sites" are examined (see FSM 2361.7 [1983]). Permit compliance procedures require that the environmental situation and archaeological characteristics of a cultural resource be described in terms of the categories specified on the **Archaeological and Historical Site Inventory Form** (R3-2300-2 [6/80]). Page 1 of the form (all of "Card 1" and over one-half of "Card 2") pertains to administrative or environmental data, which are unquestionably important for management purposes (Cordell et al. 1984:90).

Page 2 of the form (part of "Card 2" and all of" Card 3") is devoted to categories "that will allow for a rather detailed coding of the description of the site from its general class through its more detailed use and type" (FSM 2361.7 [1983]:39). The categories on page 2 were designed, evidently, to compile data that pertain to only one major source of archaeological variability -- function (USE). These so-called USE categories, unfortunately, are not mutually exclusive (see also Dean 1978:110-111). For example, what are the differences between the limited activity, specialized activity, and water-soil control USE taxa? This problem applies to the TYPE categories as well. For example, what are the differences between knapping [006] and manufacturing [167] as types of limited activity sites? Second, they are not operationalized to the extent that a surveyor could reliably tag a cultural resource according to one of the USE categories. For example, which attributes of a cultural resource pertain to limited activity "use" and which to habitation "use" or various combination thereof? Third, because different systemic sources of variability may produce similar archaeological remains (Sullivan and Schiffer 1978:168-169), the USE and TYPE categories obscure potentially meaningful variation (Sullivan 1987a). Fourth, as is implied by their labels, the USE and TYPE categories are not interpretation-neutral, and thereby bias or render uncertain any inferences based on them (Plog et al. 1978a:142). In summary, current Forest Service site definitions and characterization

procedures, which provide more than enough information for management purposes, are insufficient for addressing contemporary research problems in settlement archaeology (cf. Plog et al. 1978b).

CHARACTERIZING THE ARCHAEOLOGICAL RECORD: BEYOND THE FOREST SERVICE VERSION OF SARG

In order to overcome the limitations of the Forest Service's version of the SARG paradigm (Sullivan and Schiffer 1978), and to enhance the research potential of cultural resources on Forest Service land, alternative approaches to survey and settlement archaeology need to be explored. The particular view advocated here contrasts with the Forest Service's in several important respects. An examination of these points of departure illustrates why an alternative approach would benefit the research and management concerns of the Forest Service.

This approach is based on new understandings of how societies interact with their surroundings and how such interactions affect the character of the archaeological record (e.g., Graham and Roberts 1986:108ff). For example, as a result of a substantial amount of research on the ethnoarchaeology of land-use (e.g., Binford 1982; also Torrence 1983), it is clear that people of non-industrial, small-scale societies spend a considerable amount of time away from their perennial settlements or home bases (see especially Eder 1984), and, furthermore, that extensive land-use is a common feature of all human societies, be they hunter-gatherers or farmers (e.g., Martin 1985; Ferguson and Hart 1985). With this perspective, sites are but "points on the landscape where a high frequency of activity occurs, and the differences between various parts of the landscape become ones of degree and not kind" (Foley 1981:2). Furthermore, as an alternative view on land-use and the formation of the regional record, the post-SARG paradigm affects considerably how units of observation are defined and how they are to be operationalized. For example, description focuses on characterizing variation in the attributes of cultural resources regardless of their clustering (Dunnell and Dancey 1983:273). The post-SARG paradigm also avoids the problem of pigeon-holing high density clusters, which often have properties that overlap among non-discrete site types (FSM 2361.7:39-42), into a single taxon (Sullivan and Schiffer 1978).

Also, the post-SARG view of settlement archaeology enhances our ability to identify which sources of variability may have affected the evolution of regional landscapes and how those sources may have changed over time (Scovill et al. 1977:45). These sources of variability include the following (Sullivan 1987b):

a) functional variability, which refers to the nature and range of activities conducted at certain locations;
b) occupational variability, which refers to how long, how intensively, or how frequently a particular location was inhabited;
c) organizational variability, which refers to how societies schedule or allocate their time and labor during the execution of different activities;
d) cultural variability, which refers to how different societies used the same landscape.

Characterization procedures based on the post-SARG paradigm generally entail some form of artifact inventory. Sometimes, the artifact content of all but the largest and densest clusters of artifacts can be exhaustively enumerated (e.g., Downum and Sullivan 1988). For large and dense artifact clusters, a form of intensive transect or grid recording may be especially useful (e.g., Rankin 1986:31-32; also Cowgill 1985:384). Thus, in contrast to the site characterization procedures outlined in FSM 2361.7 (1983), the inventory method actually counts the number of artifacts of different types that are present on the ground's surface (e.g., Wilcox et al. 1981). In fact, it is a standard procedure of some intensive surveys to obtain frequencies of ceramics (preferably by type), flaked stone artifacts (debitage, cores, unifacial tools, bifacial tools), groundstone artifacts (e.g., manos, metates), and other miscellaneous large (e.g., hoes, worked stone) and small (e.g., shell, bone, etc.) artifacts (Camilli 1988; also Downum and Sullivan 1988). The importance of artifact type and class frequency data is that they facilitate, by conversion into percentages (Thomas 1985:242), the derivation of a number of key variables, such as sherd/lithic ratios (e.g., Synenki 1984), decorated/undecorated ceramic ratios (e.g., Powell 1984), and multiple artifact class (MAC) or non-MAC areas (e.g., Czaplicki and Heathington 1986:36-40), that increase the archaeologist's ability to understand how different sources of variability have affected regional archaeological data (Sullivan 1987b).

NEW DIRECTIONS IN FOREST SERVICE ARCHAEOLOGY

Current Forest Service views on survey and settlement archaeology have been examined with respect to their underlying assumptions about what the archaeological record represents in terms of human behavior and land-use. Under the management view of the archaeological record, site definition and site characterization procedures (see FSM 2361.7 [1983] and FSH 2309.24 [1987]), which are remarkably similar to those of SARG (see especially Gaines 1978), are of limited interest to research archaeologists. First, the paradigm is flawed by its untenable view that decision-making, especially with regard to the location and formation of "sites," is influenced primarily by resource optimization strategies (e.g., Plog and Hill 1971:13). Clearly, a variety of factors, other than propinquity to so-called critical resources, affects the deposition of material culture across a landscape (Sullivan and Schiffer 1978). As Johnson (1977:501) has argued "most models of locational behavior are essentially unverifiable in that for the sake of generality they involve assumptions which are untestable or which cannot be expected to be met under real world conditions." Second, the SARG paradigm is only partially explanatory in view of its focus on functional variability as the primary factor affecting the properties of the regional resource base (e.g., Upham 1984). Ethnoarchaeological (e.g., Ebert 1979) and archaeological studies (e.g., Sullivan 1987a) have shown that the nature of the regional record can be affected by different sources of variation and interactions among them.

Problem-oriented research in settlement archaeology is hampered significantly by a focus only on the distinction between sites and phenomena that are not sites (e.g., Downum 1986:216). As Dunnell and Dancey (1983:274) have argued, "important elements of the total archaeological resource will be purged or simply mismanaged because they are not easily incorporated within this system." Because of its current emphasis on high-density artifact clusters or "sites," there is thus a danger of biasing the range of cultural phenomena that the Forest Service is charged with managing.

An alternative perspective of the regional resource record, which has benefits for managers and researchers alike, is based on new views of how human societies -- especially those with broad-spectrum subsistence economies (see Jorgensen 1983) -- "work" environments. As noted above, results from ethnoarchaeological studies of land-use (e.g., Binford 1983; Eder 1984; also Martin 1985) have alerted archaeologists to the functional, occupational, and organizational factors that affect variation in the material connections among technology, activities, and land-use (e.g., Jarman et al. 1972:61-62). After all, the primary evidence that guides Forest Service management decisions is variation in technologies (material culture design) that developed, presumably, to solve problems of human adaptation (e.g., Oswalt 1976). There appears to be no **a priori** basis, therefore, to disregard certain aspects of the cultural resource base -- any "techno-unit" may have been important depending upon the problems that the designers of the technologies were attempting to solve (e.g., Winter 1983). Also, recent research has shown that decisions affecting the design of technologies, as well as the factors that influenced where certain technological elements were discarded or abandoned, depend on a number of considerations, such as mobility (Kelly 1983) and hunting ranges (Binford 1979). In order to identify "significant" cultural resources it is essential to consider the possibility that a range of factors, beyond those generally represented at high density artifact clusters, affected the composition of the regional archaeological record (see especially Camilli 1988).

Given this alternative view of how the regional record may arise, it was suggested that new methods be considered for characterizing cultural resources on Forest Service land. One of the major features of the landscape approach is that it attempts to identify and control known sources of variability. As a result, bias is reduced in the range of resources that should fall under the Forest Service's preservation mantle. In order to provide high-quality data that would be useful to researchers and managers, the Forest Service should consider adopting, or at least testing, the inventory method for characterizing artifacts and artifact cluster assemblages that are encountered during survey. With the inventory approach, characterization moves beyond a typological approximation exercise that focuses on the "site" exclusively (FSM 2361.7 [1983]:43). Cultural resources, regardless of their degree of artifact clustering, can be described in terms of

artifact class (or type) frequencies and percentages. In this way, attributes of past cultural landscapes are developed that do not depend on subjective field decisions (see Wilcox et al. 1981).

CONCLUDING REMARKS

In closing, it is crucial to stipulate that these suggestions and alternatives have been offered to enhance the management of a broad range of cultural resources -- not just "sites" (Plog 1974:71) -- and to facilitate the investigation of some of the factors that influence the evolution of cultural landscapes. It is clear that management responsibilities must be expanded to include "less densely concentrated" aspects of the archaeological record, thereby reducing bias in what is managed and what is preserved. If we assume that management policies do not define research problems but do affect how the regional cultural resource record is characterized, then the adoption of the post-SARG paradigm should satisfy managerial requirements and the data requirements of archaeological research. In this way, both cultural resources management and cultural resources research will truly contribute to the substantive knowledge and theoretical development of archaeology.

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Cultural Resources "Catch-22" and Empirical Justification for Discovering and Documenting Low-Density Archeological Surfaces[1]

LuAnn Wandsnider[2]

Abstract.--High-density remains are well represented in the current cultural resource data base, but are poorly described. Low-density remains are well described, but are not reliably represented. Both descriptive resolution and complete representation cannot be increased for both at this time. This paper demonstrates, however, that it is essential and possible to deal more effectively with sparsely distributed cultural resources, which afford a unique perspective on the past and which cannot be protected through avoidance.

INTRODUCTION

Cultural Resource Management on the Forest and elsewhere is in a classic "Catch-22" situation. Resources that are well-represented in the cultural resource data base, i.e., high density remains, are those for which minimal documentation is available. Resources that are well-documented, i.e., low-density remains, are those that are unsystematically represented in our data base or are represented at a very low level relative to their occurrence on the ground. Resources for which the documentation enters the cultural resource filing system, i.e., sites, are also those for which protection through avoidance is commonly recommended, although this may vary by Forest and by Federal agency. Resources that are not classified as sites do not enter the cultural resource filing system and are often not protected. Current discovery and documentation practices, discussed in greater detail below, result in a cultural resource data base with a very curious and uneven character. Yet, with this data base, management decisions are made that directly impact the present conservation and future collection of cultural resource information.

This paper discusses the quality of the document of cultural resources on the Forest with specific reference to differential discovery and documentation. General statements about the treatment of cultural resources with different characteristics are presented. It is suggested that it may be desirable, for both management and research purposes, to maximize both the representativeness and quality of the cultural resource document for the Forest. Such an effort, it is recognized, is neither feasible nor practical for all cultural resources on the Forest. For low-density cultural resources, however, where avoidance is untenable, such high-resolution documentation is critical. Support for this statement comes from the unique contribution towards understanding the past that is offered by this kind of resource. Low-density archeological remains are a different kind of archeology not duplicated in high-density cultural resources, as demonstrated here by the results of several survey projects from the American West. Such resources should therefore be treated with the same reverence that higher-density remains presently are accorded. By taking steps to ensure representativeness, upgrading and standardizing documentation practices, and by allowing this information to be accessible within a filing system, low-density archeological remains can, with very little additional effort on the part of Forest CRM specialists, provide important and unique information about past use of the Forest.

CULTURAL RESOURCES DISCOVERY

Discovery of cultural resources has obvious implications for its protection from subsequent activities that occur on the Forest. Cultural resources cannot be actively protected if they have not been detected. Present discovery procedures involve the actual sighting of a surface manifestation of a cultural phenomenon. This sighting event, however, is influenced by several interacting factors as discussed by Plog,

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[1] Paper presented at the symposium entitled "Beyond Boundaries in Time and Space: The Utility of the Site Concept" at the 53rd Annual Meeting of the Society for American Archaeology [Phoenix, Arizona, April 28-May 1, 1988] and at the USDA Forest Service Cultural Resources Research Symposium [Grand Canyon, Arizona, May 2-6, 1988].

[2] LuAnn Wandsnider is Assistant Forest Archeologist for the Cibola National Forest, Albuquerque, New Mexico.

Plog, and Wait (1978), Schiffer, Sullivan, and Klinger (1978), and others. In the following discussion, I will highlight artifact/feature obtrusiveness, artifact clustering/dispersion, and surface visibility as factors that most directly influence discovery bias in low- and high-density distributions of archeological materials.

Obtrusiveness refers to the extent that a cultural resource element, an artifact or feature, contrasts with the environment or context in which it is located. By virtue of their obtrusiveness (Schiffer et al. 1978), architectural remains are more easily discovered than artifactual remains. At the same time, obtrusive artifacts, i.e., those that are large or otherwise conspicuous, are more easily found than small artifacts. The data in figure 1 come from two distributional surveys (the Seedskadee Project and Navajo-Hopi Land Exchange Project, discussed later) in which artifact discovery consisted of two passes through the survey unit. The first was a systematic pass, during which time all discovered artifacts were flagged in orange. It was followed by an unsystematic pass, during which time flagged items were field-analyzed and more artifacts were found, flagged in red, and analyzed. Most large artifacts were discovered during the first pass through the survey unit. For small chipped stone artifacts, between 40% and 50% of the total number discovered during all passes were found during the first pass. Foley (1983) has noticed a similar tendency and other attributes of artifact coloration with respect to discovery are discussed by Camilli and others (1987).

At the same time, individual artifacts belonging to an artifact cluster are more easily found than dispersed artifacts. Figure 2 is derived from an experiment in which artifacts, painted washers and nails, were introduced into a survey unit prior to survey (Wandsnider and Ebert 1984). Only 22% of those artifacts seeded so as to represent "isolated finds" were recovered by the survey crew, who used intensive (5 m transect interval) survey methods. Of those artifacts introduced onto the landscape as artifact clusters, the percentage of artifacts discovered increased with the density of the artifact cluster (fig. 2).

Surface visibility will also influence discovery of cultural resources. In his survey of both grassy and non-grassy areas within the Amboseli Reserve in Kenya, Foley (1983) observed that higher artifact densities were found in the latter. He used multiplicative factors to control for the differential discovery of artifacts, which he attributed to the presence/absence of surface cover. Geomorphological processes may introduce a similar surface visibility bias. Figure 3 presents the distribution of site sizes recorded on the Cibola National Forest. The distribution varies according to depositional and erosional context. The classification of site context was

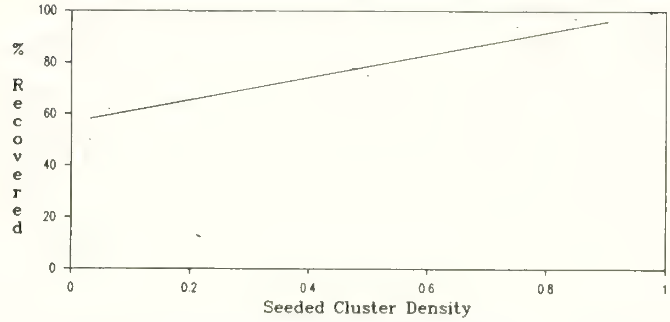


Figure 1.--Percent artifacts discovered vs. seeded cluster density (artifacts / sq m) from the Seedskadee Project seeding experiment.

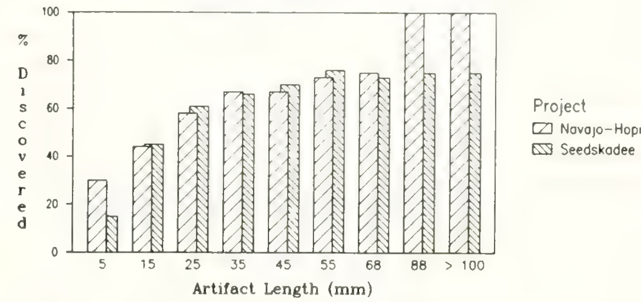


Figure 2.--Percent orange-flagged chipped stone artifacts vs. artifact length for the Navajo-Hopi Land Exchange and Seedskadee Projects.

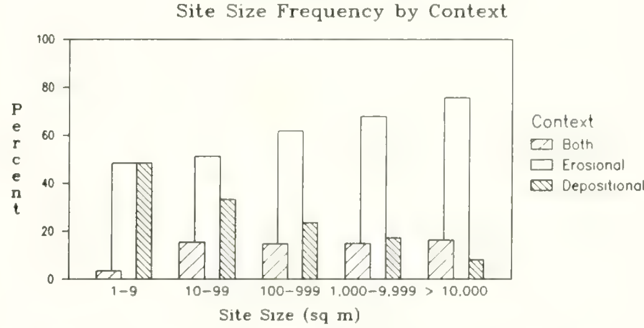


Figure 3.--Size distribution of Cibola National Forest sites with respect to depositional and erosional contexts and contexts that are both depositional and erosional.

derived from the Landform variable on the Forest site form. Sites recorded as small are found in equal proportions in depositional and erosional environments. These relative proportions change as recorded site size changes. Sites recorded as large are more often found on landforms classified as erosional rather than depositional. Does this pattern reflect

differential use of the landscape by past cultures? Or, is this pattern attributable to surface processes that have left exposed only a small portion of an expanse of cultural remains that lie just beneath the surface in depositional contexts? Insufficient data exists at present to resolve this question.

Each of these factors of obtrusiveness, local density, and surface visibility conspire to imbue different cultural resources with varying potentials for discovery. Thousand-room pueblos located on devegetated plains have the highest potential for being discovered and, in most cultural resource data bases, are the earliest entries. A few biface thinning flakes, left behind in what has come to be a Ponderosa forest, have the lowest potential for discovery. Few cultural resource data bases will contain this item.

Table 1.--Documentation of cultural resources according to characteristics of element frequency and area of dispersion. Slash (/) indicates either/or.

	Cultural Resource Characteristics			
Document	High Element Frequency		Low Element Frequency	
Dimensions	Small Area	Large Area	Small Area	Large Area
Gross Location	X	X	X	X
Fine Location			X	X[1]
Detailed Description	No/Sample	No/Sample	X	X
Accessibility	X	X	X[2]	X[3]

[1]Elements of the cultural resource may or may not be finely mapped. If status is that of an isolated find, gross mapping and fine mapping may be one and the same.

[2]If recorded as a site, the cultural resource is accessible in site file system and survey report. If recorded as an isolated find, cultural resource documentation is available in survey report.

[3]If recorded as part of one site, cultural resource is accessible in site file system and survey report. If recorded as multiple isolated finds, cultural resource documentation is in survey report.

CULTURAL RESOURCE DOCUMENTATION

Once discovered, no matter the difficulty of discovery, cultural resources with different perceived characteristics are treated differently. The following generalizations about documentation procedures are based on limited experience in working with the New Mexico ARM file system and the Cibola Forest site file. Four dimensions of documentation can be identified and include: 1) the gross location of cultural materials on the landscape (e.g., the dot on the USGS 1:24,000 map), 2) finer locational information for elements of an archeological assemblage (e.g., the site map), 3) descriptive information about the contents of the assemblage, and 4) accessibility of that document to those who wish to use information about the kind and distribution of cultural materials. By accessibility of documented information, I refer to whether that information is placed into and retrievable through a systematic filing system.

Cultural resources with different densities and frequencies are differentially documented with respect to each of these four dimensions as summarized in Table 1. Gross locational information is available for most cultural resources. The accuracy of this locational information is probably highest for those cultural resources that occur over a large area, due to the nature of mapping small-area phenomenon at large scales. That is, it will be more difficult to relocate an isolated find (or even a single-room feature) using its mapped location on a USGS quadrangle than it will be to find again a lithic scatter dispersed over 10,000 sq m.

Locations of individual elements of an assemblage are mapped if the economics of the situation permits it. I use the term element to refer to each of the artifacts and features that contribute to an assemblage. As the number of artifacts and features increases, the resolution of spatial information decreases because it takes more time to map more items and recording time is limited, and because current management practices make detailed documentation unnecessary (see below). If artifacts or features are widely distributed over an area and no clustering is evident, these may or may not be individually mapped. If mapped, they may be termed isolated finds, in which case a gross location would be secured for each, or they may be mapped as elements of one large, amorphous site.

Descriptive resolution of assemblage elements likewise changes with element frequency and relative density. A single artifact or feature may be described in detail. Conversely, a dense scatter of artifacts may be grossly described as to relative frequencies of artifact type **x**. Alternatively, a sample, biased or unbiased, of the dense artifact scatter may be described in detail.

Accessibility of documented cultural remains depend upon decisions as to their status. Those remains ascribed the status of "site" may find their way into a systematic inventory of sites kept either by the Forest and/or the state in which it was located. Those termed "isolated finds," while available in unpublished survey reports, are usually otherwise inaccessible.

To summarize, we have good gross locational information about all cultural resources. Cultural resources with few elements are well described and often individually located so that structural information about the assemblage is available. These resources, however, may or may not be accessible in a paper or magnetic archive of cultural resources. Conversely, cultural resources with many elements are often not well described, are usually not individually located (but may be mapped according to intra-site areas or loci), and, since these usually are described in terms of sites, will be incorporated into a site filing system. Those items that are best described and mapped, if termed isolated finds, are those remains that are least accessible.

Those resources, which by virtue of their size or complexity are most likely to be poorly described and only grossly located, are those that are accessible in filing systems.

This unequal treatment of cultural resources in terms of documentation procedure reflect management decisions that have to do with which cultural resources are avoided and which are not. These management decisions have two aspects, each of them related to the eligibility of a resource for nomination to the National Register. Aspects include the cost of adequate documentation and the implicit assumption that the more elements at a place, the more important the place. Each of these aspects is examined in turn.

A decision about which cultural resources to preserve through avoidance and which to preserve through extensive documentation rests on economics and a determination of eligibility or potential eligibility of a resource for National Register nomination. On the Cibola Forest, the CRM policy of which I am most familiar, all high-density cultural resources designated as sites are considered to be potentially eligible to the National Register under Criteria D (research potential), if for no other reason, and are treated as such. Such a policy internalizes the observation made by Tainter (this volume and elsewhere) that future research data requirements cannot be anticipated. On other Forests and for other Federal agencies, the eligibility of the site may be evaluated on a case by case basis. All sites determined eligible or potentially eligible, however, either must be avoided or their information potential conserved through adequate documentation. The more material there is to document, the more it will cost to document those resources. Therefore, avoidance is least costly in terms of dollars spent and in terms of the conservation of a nonrenewable resource. Where possible, avoidance is the preferred form of preservation (but see Spoerl, this volume).

The other "Tutonic" aspect to management decisions, that more artifacts or more features have more intrinsic importance than a few of the same and therefore should be avoided, is not explicitly articulated anywhere that I can find, but is present nevertheless. For example, I have had conversations with archeologists in the Forest Service, in other Federal agencies, in the private sector, and in academic institutions, and with representatives of the State Historic Preservation Office in New Mexico in which this sentiment is expressed. It likewise permeates, but is nowhere expressed in, documentation concerned with nomination of cultural resources to the National Register of Historic Places. The reasoning behind this feeling is not clear but may have to do with notion that the amount of information about the past is directly and incrementally related to number of assemblage elements. This reasoning also holds that a single feature contains more information than a single artifact. The perceived low information content of few element cultural resources may be because these remains are seen to represent accidental (e.g., projectile point loss or "pot drop") rather than deliberate activities. Or, these remains are felt to be from limited or special as opposed to residential activities, the latter being somehow more important than the former. Within formation process archeology, however, a loss event is just as important as a production event; both contribute to the form of the archeological record (Schiffer 1987).

The relationship between number of archeological items in an assemblage and its information content is a complex topic that will be addressed elsewhere. For the purposes of this discussion, however, I suggest that this relationship requires definition. The following examples of archeological assemblages with varying density characteristics, however, tend to support the opposite. That is, they suggest that low-frequency and low-density archeological materials provide unique insight into past uses of the landscape and are therefore just as rich in information as cultural resource deposits with large numbers of assemblage elements.

EXAMPLES OF ARCHEOLOGICAL SURFACES

The following examples are derived from several cultural resource management projects and one "pure" research project that have been conducted throughout the western United States. Except for the latter, the areas in which these projects were conducted are arid and the largest "trees" found here are greasewood, sage, and mesquite. That is, these cultural resource data were collected under optimal conditions of surface visibility, which are infrequently found on the Forest. The other research project occurred in southeastern Oregon and in addition to sage and desert scrubland, stands of juniper and aspen were surveyed.

Figure 4 considers assemblage content according to relative artifact density for the Bureau of Reclamation San Luis Valley project in

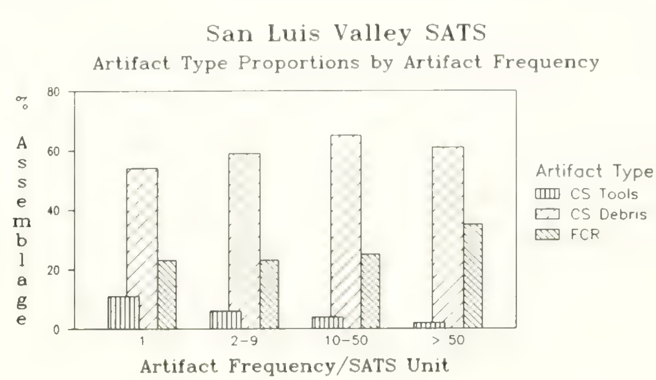


Figure 4.--Artifact type proportions vs. artifact frequency from the San Luis Valley Systematic Aligned Transect Survey.

south-central Colorado (Button 1987). In this instance, artifact frequencies are derived for each unit of systematic aligned transect survey (SATS). One SATS unit was surveyed with 5 transects, each 6 ft. by 528 ft. and spaced 100 ft. apart. Overall, chipped stone tools contribute little to the total assemblage makeup. Assemblages from those areas with low-artifact density, however, are different from high-artifact density areas. In the former, chipped stone tools comprise a larger proportion of the surface assemblage than for the latter areas. As artifact density increases, this density is contributed to more heavily by first chipped stone manufacturing debris and then fire-altered rock.

As similar tendency is seen in figure 5, which presents assemblage information for the Bureau of Reclamation Seedskadee project area located in southwestern Wyoming (Drager and Ireland 1986; Wandsnider and Larralde 1986). These frequency data were derived from a grid of 25-m cells imposed on distributions of more than 17,000 point- and one meter cell-provenienced artifacts. The surface assemblage of low-density cells are composed of relatively more formal and informal chipped stone tools than is true of high-density cells. As density increases, chipped stone manufacturing debris comprises more and more of the assemblage. Cell assemblages with very high densities contain high proportions of fire-altered rock.

At least for the Seedskadee data, artifact density seems to bear little relationship to the portion of the tool found. Other studies (Torrence 1983; Binford and O'Connell 1984) have suggested that tool refurbishing will occur during downtime while other activities are underway or in the course of gearing-up activities at the residential base. In addition to other qualities, each of these sites would be expected to have relatively high artifact densities, if they were used for any length of time. Therefore, it is expected that tool portions such as projectile point bases should be found in areas of relatively high artifact density. Whole points are often thought to be due to loss and therefore might be expected to be found in places with low-artifact density. A

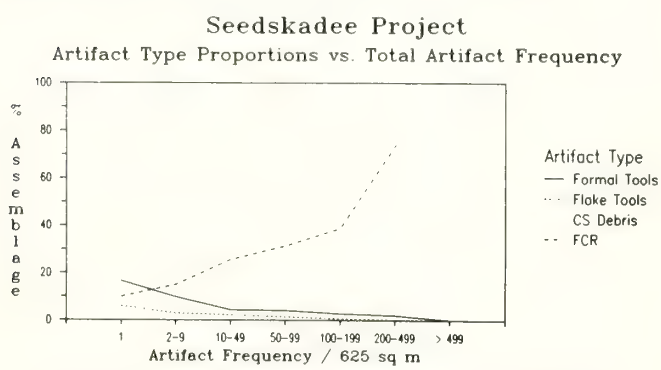
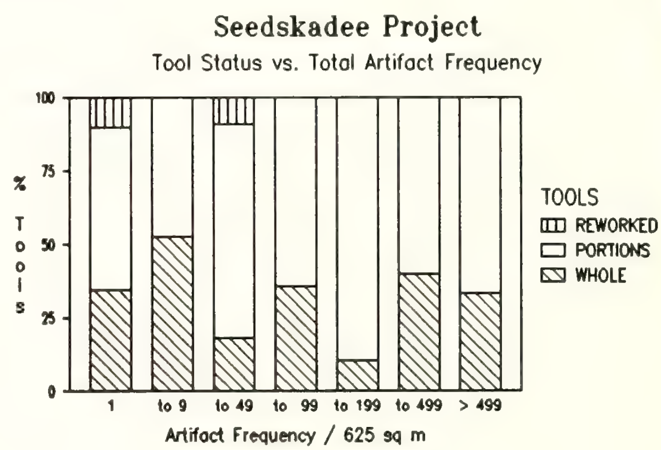


Figure 5.--Artifact type proportions vs. total artifact frequency for Seedskadee grid cells.

consideration of Seedskadee chipped stone tools shows little association between artifact density and either tool status (fig. 6A) or tool portion (fig. 6B). This patterning suggests that assemblages that appear to be both low- and high-artifact density are at locations where tool refurbishing or loss occurred. Or, it suggests that artifact density, as an indicator of "people time" spent at places, requires examination. Or, the conditions under which tool portions enter and leave the archeological context (Schiffer 1972) demand more investigation.

Previous examples have dealt with artifact densities as estimated for areas with specific dimensions. When the respective assemblages of sites vs. isolated finds are considered, a similar trend emerges. The data presented in figure 7 come from the Steens Mountain Prehistory Project (Jones 1984: Tables 5.3-5.7, 5.11, 5.13, 5.17), conducted in southeastern Oregon. Low-density areas were recorded as off-site areas, while high artifact density areas were recorded as sites. Almost all artifacts from both areas were collected for laboratory analysis. For some site areas, however,



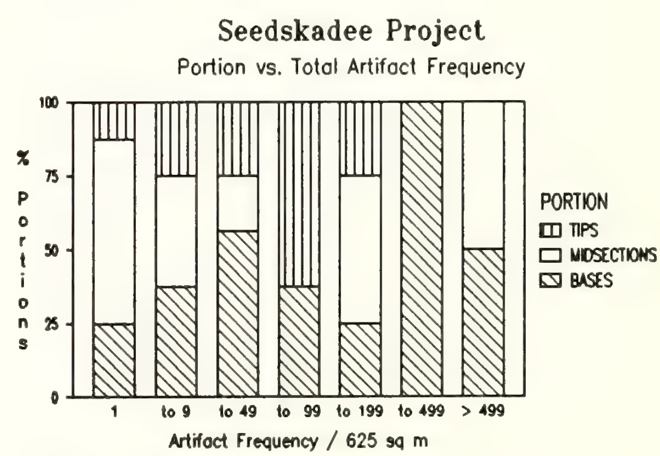


Figure 6.--Seedskadee chipped stone tools with (A) tool status vs. artifact frequency per grid cell and (B) portion percentages vs. artifact frequency per grid cell.

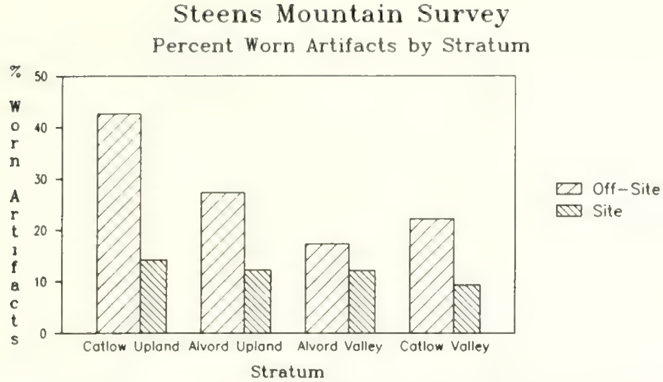


Figure 7.--Percent worn chipped stone artifacts by stratum for Steens Mountain off-site and site survey areas.

artifacts were collected according to various sampling schemes. In the figure 7, only those sites for which all artifacts were collected are included in these calculations. In off-site areas, the proportion of worn artifacts is higher than that found in sites, when geographic stratum is held constant. The variability in proportions between strata are interesting in and of themselves but do not directly relate to the point to be emphasized here. This point is that off-site or low-artifact density areas have a very different artifact assemblage than site or high-density areas.

Data from the Navajo-Hopi Land Exchange project in south-central New Mexico show a similar tendency. Artifacts were provenienced to the nearest centimeter or meter in this project and were described in detail in the field. Coordinates for each artifact where forced into spatial clusters using proximity criteria (see Camilli et al. 1987). Those artifacts that could not be clustered by the algorithm consist of proportionately more formal chipped stone tools, informal flake tools, and groundstone (fig. 8). In clustered assemblages, relatively more ceramics and fire-altered rock occur.

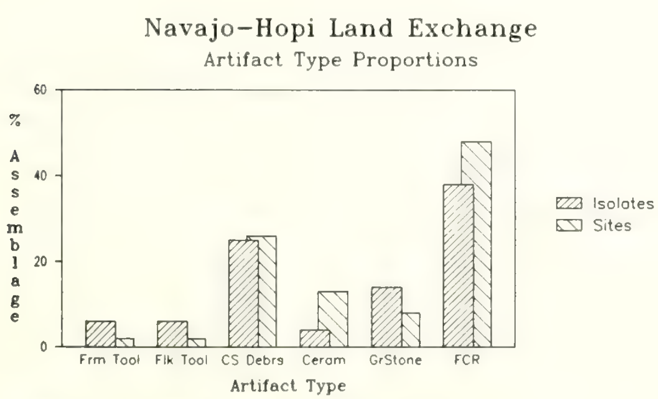
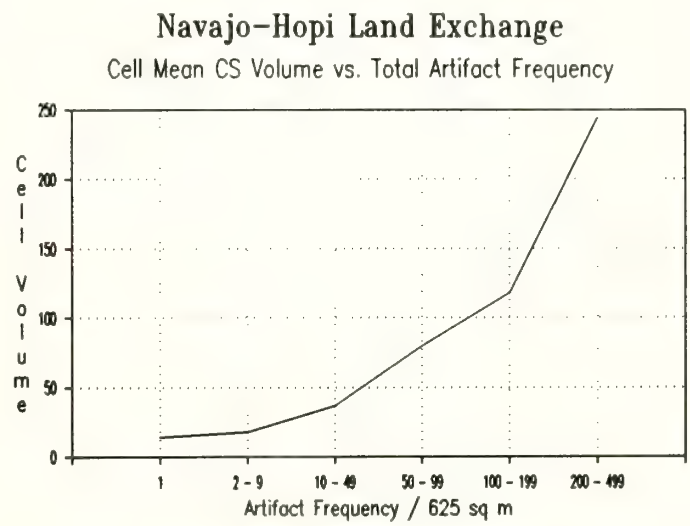


Figure 8.--Navajo-Hopi Land Exchange artifact type proportions for derived "isolated finds" and "sites."

When artifact density, derived for 25-m grid cells, is considered for Navajo-Hopi archeological surfaces, relationships between local artifact density and volume of chipped stone can be discerned. As artifact density increases, the average total amount or volume of chipped stone material for which metrics were recorded likewise increases (fig. 9A). Chipped stone volume was calculated by adding up for each grid cell all chipped stone volumes estimated by the multiplication of artifact length, width, and thickness. At the same time, individual chipped stone artifact size decreases with increasing artifact density (fig. 9B). Low-density areas are characterized by a few large chipped stone artifacts; high-density areas are characterized by many, many small pieces of chipped stone. Frequencies and sizes for those chipped stone artifacts such as angular debris, which were assigned to a gross size class, mirror this same tendency.



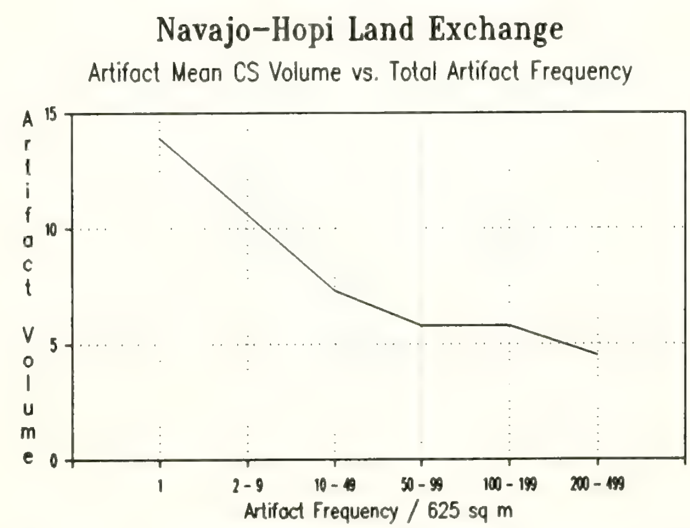


Figure 9.--Navajo-Hopi Land Exchange chipped stone volumes vs. total artifact frequency per grid cell for (A) cell mean volume and (B) artifact mean volume.

DISCUSSION

The patterns evident in the above examples are both mundane and surprising. One one hand, we know that chipped stone manufacturing entails the production of large quantities of waste material. Likewise, plant processing that employs heated rocks rarely generates a few fire-altered rock and more commonly generates a quantity of fire-altered rock. It is therefore not surprising that when an archeological assemblage is made up of many artifacts, those artifacts are referable to activities that generate large quantities of non-biodegradable by-products. On the other hand, the relationship between assemblage density and assemblage makeup, in that it is found in all assemblages considered, is interesting and informative. It suggests that no matter where or how one looks, low-density phenomenon are not a sparser version of high-density archeological materials. That is, they are unique.

This patterning inspires several observations. First, site definition criterion, which usually focus on relatively high artifact densities, should entail that locations where chipped stone manufacturing and food processing using hearth rock should be very well-represented in our site files. Low-density cultural remains, where perhaps isolated as opposed to recurrent activities occurred in the past, are under-represented because our discovery methods do not find them. When they are found, they are called isolated finds and therefore do not enter the cultural resource filing system. It is unlikely, therefore, that the patterns described here, which relate assemblage density and assemblage composition, could be discernible in the current data base. Yet, such patterning provides a vital clue as to past uses of the landscape and to present analytic needs to understand such variability.

Secondly, we have few modern referents for chipped stone tool manufacturing, use, and discard. While there are modern peoples who use ceramics and groundstone, it is not necessarily the case that those items function in the technological system in capacities similar to their prehistoric counterparts. This possible difference in tool role is due to the fact that other aspects of the cultural system, e.g., subsistence and mobility, are likely very different today than in the past. For us to understand the role that tools of any type played in past cultural systems, inductive analytic strategies, grounded by knowledge of how other tools function in modern systems, must be employed. In any inductive analysis, the referential domain of the varying data items structures and enlightens the analysis. The archeological context of assemblage elements is therefore critical to this analysis and many different kinds of contexts, low-density, high artifact density, with structures and features, without structures and features, etc., are likewise vital.

IMPLICATIONS FOR MANAGEMENT

If it is agreed that low-density cultural remains are an important source of information about the use of the Forest by past cultural groups, implications for cultural resource management can be far-reaching. Both current discovery and documentation methods would be affected.

At present, discovery methods are not geared towards locating all low-density cultural remains. Because of the factors of obtrusiveness, relative density, and surface visibility discussed at the outset, even intensive survey yields only a small proportion of elements that actually exist in low-density situations. The moderate intensity at which survey is conducted on the Forest can be expected to return an even smaller proportion. Yet, this moderate intensity may be sufficient for capturing the information content of this unique cultural resource. If it can be demonstrated that located items faithfully represent, at some low and unvarying level, the total population of surface elements, than moderate-intensity survey can suffice. That is, if with increasing coverage the same relative proportions of elements are found, than a moderate-intensity survey may produce as much information as a high-intensity survey, at least with respect to non-clustered remains. The fact that increased survey intensity usually results in increased artifact densities, would have to be taken into consideration in the course of this evaluation.

A demonstration of the above may in fact show that moderate-intensity survey cannot reliably find low-density or sparsely distributed remains. In this case, it may be worthwhile to increase survey coverage in those specific situations where optimal surface visibility exists. Where visibility windows have been provided, due to fire, or where artificial erosional surfaces have been created, as with disking operations, survey intensity may be profitably increased.

The major modification to current Forest Service cultural resource management lies in the documentation and accessibility of documented materials for low-density remains. Introduction of a standardized recording format for those resources ascribed the status of isolated finds might be the first step. The second might be the creation of an isolated find file to be maintained concurrently with a site file. With such a system in place, the unique information provided by low-density remains will not be totally destroyed, even if the remains themselves are. Geographic Information System (GIS) technology lends itself nicely to the inventory and data management of both low- and high-density phenomenon. Integration of cultural resource locational and descriptive information, at a scale of resolution of use to managers, into the total fabric of resource management could be facilitated in this way.

High-resolution documentation is an acknowledged means of cultural resource conservation when avoidance is impossible. This paper has attempted to demonstrate that this same rationale for dealing with high-density cultural remains should be extended to low-density cultural resources, since they provide unique information on the past. Throughout this paper I have referred to low- and high-density cultural resources as though they were separate entities that could easily be distinguished in the field. In reality, each of these represents polar extremes on a continuum of density (Dunnell and Dancey 1983). Technology is rapidly becoming available that will permit the cost-effective documentation of cultural resources along this density continuum in an atomic, i.e., element by element, fashion. By taking steps now to deal with the issue of discovery and documentation of sparse distributions of cultural resources, the Forest Service can anticipate and participate in the development of this new technology. More importantly, it can take measures to conserve information about the past that is as irretrievable as that found in high-density cultural resource deposits and is perhaps more easily managed.

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Landscape Archaeological Research and Cultural Resources Management[1]

Alan P. Sullivan, III[2], Mark A. Calamia[3], Bruce R. Donaldson[4], Paul R. Fish[5], Emily Garber[6], John A. Hanson[7], Susanna R. Katz[8], Carl J. Phagan[9], and LuAnn Wandsnider[10]

Abstract. -- Forest Service cultural resource research should focus on three priority problem domains: (1) cultural resource discovery, (2) cultural resource characterization, and (3) natural resource discovery and characterization. A research program is described that entails the establishment of Cultural Resource Research Areas (CRRAs) to serve as dedicated laboratories where experiments can be conducted that pertain to each problem domain.

INTRODUCTION

Current Forest Service procedures for discovering and characterizing the regional archaeological record may not support a full range of management options. Some specific difficulties that we have identified pertain to questionable assumptions about how people have used land in the past and to the interpretation of the material results of past land-use (Sullivan, this volume). One of the most significant problems is that the unit of documentation currently used by the Forest Service -- the "site" -- may be needlessly exclusionary and incapable of accommodating all of the cultural remains on Forest Service land. As a result, survey and inventory strategies that employ the site as a clerical taxon may not produce reliable, consistent, and replicable results.

CULTURAL RESOURCE RESEARCH AND LANDSCAPE ARCHAEOLOGY

In response to these and other problems (see Priority Research Problems below), we propose the following research program. The primary goal is to provide the Forest Service with information that can be used to manage cultural resources more effectively. The objectives are to develop and test techniques and methods for discovering and documenting the full range of

[1] Paper prepared at the Forest Service Cultural Resources Research Symposium, May 2-6, 1988, Grand Canyon, Arizona.

[2] Research Associate, Laboratory of Traditional Technology, Department of Anthropology, University of Arizona, Tucson.

[3] Archaeologist, Bureau of Land Management, Carlsbad Resource Area, Carlsbad, New Mexico.

[4] Forest Archaeologist, Apache-Sitgreaves National Forests, Springerville, Arizona.

[5] Curator of Archaeology, Arizona State Museum, University of Arizona, Tucson.

[6] Forest Archaeologist, Cibola National Forest, Albuquerque, New Mexico.

[7] Forest Archaeologist, Kaibab National Forest, Williams, Arizona.

[8] Research Associate, Center for American Archaeology, Kampsville, Illinois.

[9] Research Associate, Museum of Northern Arizona, Flagstaff.

[10] Archaeologist, Cibola National Forest, Albuquerque, New Mexico.

cultural resources on Forest Service lands. Based on the results of this research program, recommendations will be made for generating information to guide management decisions regarding the allocation and disposition of cultural resources.

Our research orientation is referred to as the "landscape perspective." It assumes that human behavior is spatially continuous and can generally be inferred from the variability expressed by archaeological remains observable on the earth's surface (e.g., Foley 1981a). Furthermore, this perspective does not assume that the concept of "site" is without research and/or management value, and it does not advocate any particular theoretical model of past land-use (e.g., Jarman et al. 1972; SARG 1974; Tainter 1984). One of the many goals of the proposed research program is to determine experimentally which unit of documentation (e.g., the site, the survey unit, the artifact) is the most effective for describing certain kinds of cultural resources that are discovered under certain survey conditions.

In many respects, the landscape approach is a child of the frustration experienced by many archaeologists who have attempted to force the extensive variability of archaeological remains into ill-defined taxa. For example, a large lithic and sherd scatter is difficult to evaluate in a scheme that recognizes only habitation sites and limited-activity loci (Sullivan, this volume). In recent years, archaeologists have field-tested the landscape approach by developing methods that capture the regional distribution of archaeological remains. Thomas (1973, 1975) and Bettinger (1977), for instance, each generated models based on Great Basin ethnography that linked relative artifact density to suites of subsistence activities. Their discovery procedures were, by present standards, not very intensive (transect interval = 50 m) and the unit of provenience was a 500 m quad. Both archaeologists, however, inferred reliably that patterning in artifact density and dispersion was a result of past uses of differentiated landscapes.

Foley (1981a, 1981b, 1981c) constructed a model of regional artifact accumulation for the Amboseli region in Kenya. His discovery procedures were intensive and the unit of provenience was a relatively small 1000 sq m unit. An inventory of environmental features, such type of vegetation, soil, and lithology, was made for every survey unit whether artifacts were found there or not. The distribution of these landscape contextual variables enhanced the interpretation of spatial variation in artifact densities (see also Dancey 1973).

Irwin-Williams and her colleagues (1988) have devised a technique they term the Density-Dependent Method, which varies the nature and intensity of survey according to artifact abundance and clustering. The objective of this technique, which has been tested in central New Mexico, is to provide an accurate estimate of artifact density for each survey quadrat regardless of the distribution of artifacts within that unit. Another important component of their research involves collecting information about Landform Environment Classes (LECs), which are composites of topography, soil, and substrate, that they argue may have influenced past biotic diversity and productivity. LECs were interpreted from aerial photographs, and the analysis of artifact density and dispersion for each survey unit proceeded with respect to these landscape characteristics.

Another version of the landscape approach, called distributional archaeology (Ebert et al. 1987), involves the intensive survey, in-field description, and mapping of artifacts across relatively large expanses of land (between 0.16 h and 1.28 h). These field methods have been implemented in southwest Wyoming (Drager and Ireland 1986) and south-central New Mexico (Camilli 1988). Like Dancey's (1973) methods, they were designed to provide data on the association and covariance among different kinds of artifacts across a landscape. Aerial photograph interpretations, focusing primarily on geomorphology as a proxy for different potentials of past land-use, have framed some of these analyses (e.g., Ebert 1986; Wandsnider 1987).

These and other landscape studies share three attributes. First, all are explicitly concerned with the relationship between past land-use patterns and the present-day surface archaeological expressions of those patterns. Second, all focus on the problem of accurately and reliably measuring the density and spatial patterning of surface archaeological materials. In most cases, difficulties encountered in objectively and reliably documenting cultural materials using the site taxon prompted each of these researchers to abandon the site as the

unit of documentation. The unit of description is often the artifact and the unit of provenience may be the artifact itself or a parcel of land, such as the survey unit. Finally, all landscape studies employ environmental information, which may be obtained through a variety of methods (e.g., aerial photograph interpretation), to understand the presence/absence and regional patterning of cultural resources.

PRIORITY RESEARCH PROBLEMS

In view of the difficulties with current Forest Service cultural resource management procedures, three sets of research problems have been identified: (1) cultural resource discovery, (2) cultural resource characterization, and (3) natural resource discovery and characterization.

The first and highest priority set focuses on problems associated with the discovery of cultural resources. Contrary to the general Southwestern survey paradigm, which assumes high visibility, it is well known that throughout Region 3, cultural resources are often obscured by accumulations of leaf and needle litter or by alluvium. Related to the visibility problem is the question of how different survey (Schiffer et al. 1978) and sampling (Nance 1983) strategies affect the discovery of different kinds of cultural resources (Plog et al. 1978).

The second set of research issues is concerned with documenting the variability of cultural resources and their settings. Here, research is needed to evaluate different methods and techniques for characterizing cultural resources in an objective, non-arbitrary, and interpretation-neutral fashion. Results of this research would be especially useful in view of the difficulties presented by diffuse and expansive artifact scatters, which may be difficult to bound spatially using current techniques. Other problems in this set include (1) understanding how different factors affect the "renewal" of cultural resources once they have been observed or affected by the activities of archaeologists; (2) understanding how sub-surface archaeological variability is expressed differentially in surface archaeological variability (e.g., Synenki 1984); and (3) understanding the nature of the activities that produced small and/or low-density artifact scatters (e.g., Sullivan 1983, 1987a; Tainter 1979).

The third and lowest priority set of research problems focuses on methods and techniques for locating and recording features of the natural landscape that may have influenced the organization of past adaptive patterns and, therefore, the character of the regional archaeological record (e.g., Kohler and Parker 1986).

RESOURCE DISCOVERY

The probabilities for discovering cultural or natural resources vary depending on seasonal and spatial factors and on the physical and depositional characteristics of the material remains themselves. Our understanding of the processes that affect resource discovery probabilities, which is still emerging, has critical implications for both the interpretation and management of the regional resource base. Holding survey strategy constant, it can be assumed generally that the greatest chance of encountering cultural resources lies with material remains that are relatively large, abundant, dense, non-clustered, sharply contrastive with local vegetation, and perennially or frequently exposed (Schiffer et al. 1978). Conversely, remains that are comparatively small in area, rare, low-density, non-contrastive, and infrequently or poorly exposed have far fewer chances of being discovered.

Interestingly, research focusing on how environmental factors affect discovery probabilities has been relatively common in the Eastern Woodlands of the United States (e.g., Fish and Gresham n.d.; Krakker et al. 1983; Lightfoot 1986; Lovis 1976; Nance and Ball 1986). There, even abundant and clustered remains are frequently invisible to surface surveys because of heavy vegetation and substantial alluvial deposition. By contrast, variables affecting discovery probabilities in the Southwest have received almost no attention (cf. Schiffer and Wells 1982). Perhaps because the Southwest is viewed as an optimal situation for surface survey, reports rarely, if ever, specify any factors that could have limited the discovery of cultural resources.

A growing body of evidence, however, suggests that the prevailing Southwestern survey paradigm, with its assumptions of optimal visibility and exposed occupation surfaces, may be far too optimistic if not simplistic (Downum et al. 1986). Geomorphic maps of post-

Pleistocene land surfaces show broad expanses of deposition and erosion, even in zones outside major river valleys. Also, pine tree needles may obscure all but the most obtrusive remains in some forests, while dense grasslands present equally imposing challenges in others (Schiffer 1987).

Clearly, the landscape approach to understanding or modeling past land-use patterns requires that a familiarity be developed with those cultural resource phenomena that may depart from the theoretical construct of the **site**. This approach involves recording artifacts that may be so dispersed that they outstrip the spatial parameters for what has constituted a site but, which in the aggregate, represent related instances of an integrated behavioral complex. Such remains present difficulties in recording and analysis when our expectations of the regional archaeological record focus on the discovery of clustered artifact locations surrounded by empty space (Wobst 1983:66). Although the relatively sparse remains of hunting and gathering societies come immediately to mind (e.g., Thomas 1973), the problems of discovering and documenting the remains of those people who lived lightly upon the land are equally applicable to horticultural foragers (e.g., Sullivan 1987b) and extensive agriculturalists (e.g., Fish et al. 1985). It is essential, therefore, that experimental designs determine which survey scales, intensities, crew-spacings, and technologies (Calamia, this volume) may be the most effective for the discovery of remains representing different visibility thresholds (also Nance 1983).

CULTURAL RESOURCE DOCUMENTATION

Documentation of cultural resources is comprised of two complementary aspects: (1) description and (2) provenience. Description refers to recording pertinent attributes of the resource. Provenience refers to establishing locational information about the cultural resource.

Experiments should be designed to determine the efficacy of different descriptive methods at different levels of specificity and resolution. For example, artifacts can be classified in the field according to their major class, such as debitage, chipped stone tool, groundstone implement, and fire-altered rock (Button 1987). More comprehensive documentation might involve artifact collections and detailed laboratory analysis (e.g., Beck 1984).

Similarly, provenience information can be gathered at the scale of the survey unit (e.g., Bettinger 1977; Foley 1981b; Thomas 1973, 1975) or the artifact (e.g., Dancey 1973; Ebert et al. 1987; Camilli et al. 1987a). In some studies, the survey transect has served as the unit of provenience (Button 1987), while others have provenienced artifacts with respect to sites and non-site areas (e.g., Jones 1984).

The resolution level at which description and provenience data are collected is related to the level of effort expended in obtaining such data. Generally, as the level of resolution increases, so do costs. With the availability of microcomputer technology, however, the cost of high-resolution descriptive and provenience information has fallen dramatically (e.g., Camilli et al. 1987b) and should continue to fall. An important concern for Forest Service cultural resource research, therefore, would be to develop and test cost-effective means to acquire high resolution data regarding the following:

(1) objective and reliable criteria for establishing the spatial limits of cultural resources;

(2) variables and attribute states for describing how cultural resources are distributed across space; this may involve developing and testing a variety of recording formats and procedures;

(3) scales of provenience for documenting cultural resource locational information; this may involve exploring the efficacy of Geographic Information Systems (GIS) technology (Calamia, this volume; also see below);

(4) chronometric (e.g., obsidian hydration) and non-chronometric (e.g., seriation) dating techniques.

NATURAL RESOURCE DISCOVERY AND DOCUMENTATION

Important but often overlooked aspects of archaeological survey are observations that can be made by field personnel of the non-cultural components of landscapes. We recommend that

efforts be directed during surveys to locate and record the following potential sources of paleoenvironmental data (see also Dincauze 1987):

(1) Pollen Reservoirs: regional pollen records may enhance paleoenvironmental reconstruction (Bryant and Holloway 1983); therefore, locations that are conducive to the preservation of pollen, such as dry caves and wet marshes, should be recorded.

(2) Packrat Middens: variability in the composition of packrat middens reflects local conditions because of the restricted foraging radii of packrats (e.g., Betancourt and Van Devender 1981); therefore, locations that are likely to contain packrat middens, such as crevices and rocky ledges, should be inspected for these remains.

(3) Dendrology: the analysis of cores taken from trees growing in stressful conditions often provides time-series data about past cycles of temperature and precipitation (e.g., Dean and Robinson 1978); therefore, locations of trees that appear promising in this regard should be noted.

(4) Lithic and Clay Sources: the nature and distribution of potential sources of raw material for stone tools, ceramics, and architecture should be recorded because they may provide data for studies concerning artifact manufacture locations, and trade and exchange patterns (e.g., Toll 1981).

(5) Stratigraphic Exposures: exposures of stratigraphic sequences, such as those revealed in roadcuts and arroyo cutbanks, should be recorded for geochronological studies. Of prime importance are those exposures that include buried soil horizons, lag deposits, and other features pertaining to soil development, erosion, and climatic change (Euler et al. 1979).

(6) Geomorphic Surfaces: information about the distribution of geomorphic surfaces provides a basis for determining environmental potential and the likelihood that artifacts of different time periods may be obscured from discovery by traditional survey techniques (e.g., Waters 1985).

Because Geographic Information Systems (GIS) store, organize, analyze, and display spatial data they can be especially useful for studying landscapes (Kvamme and Kohler 1986). Information about elevation, slope, aspect, relief, hydrography, soil associations, surface geologic units, and vegetation communities, for example, can be mapped and manipulated with GIS (Calamia, this volume). With these data, the covariation of archaeological and environmental variables can be explored.

When remote sensing techniques are interfaced with GIS, they become powerful tools for the interpretation and evaluation of landscapes, which may extend over hundreds or thousands of acres. One of the goals of landscape analysis is to identify specific spectral and spatial signatures that offer clues about land-use patterns (e.g., Weymouth 1986). Remote sensing techniques can facilitate this process by increasing the accessibility to specific landscape information. Also, temporal changes to a natural landscape resulting from biotic community dynamics, grazing, logging, and fires, can be analyzed and monitored.

Recent research has enabled specialists to identify plants by means of the nearly indestructible though minute quantities of diagnostic silicate minerals they produce (Rovner 1983). Variation among phytolith assemblages, as among pollen spectra, facilitates paleoenvironmental reconstruction. More importantly, opal phytoliths often survive for identification and analysis when pollen has not. Experiments in sampling for the remains of opal phytoliths should be conducted to test the feasibility of these data for contributing, in a cost-effective manner, to regional landscape studies.

CULTURAL RESOURCE RESEARCH AREAS

We propose that Cultural Resource Research Areas (CRRAs) be reserved as temporary research laboratories or research units where controlled experiments pertaining to the prioritized research problem sets can be conducted. Initial consideration should be given to Research Natural Areas, Wilderness Areas, and other special management areas that may already exist in order to reduce or avoid potential conflicts with other uses of forest

resources (e.g., recreation, timber sales). In all cases, however, the set-aside of these research reservations will be temporary (see below).

Areal parameters will be defined by the requirements of research designs, but maximal variability within and among CRRAs is an essential aspect of their definition. As a starting point, CRRAs could be based on Terrestrial Eco-System (TES) mapping units. TES units are 40 acre (or larger) parcels of land that are homogeneous with respect to soils and vegetation; a new TES is defined wherever soil or vegetation changes. For those forests where TES mapping units are unavailable, CRRAs could be based on major vegetation communities such as upland conifer forest, oak woodland, chaparral, or savannah grasslands (e.g., Brown 1982).

We advocate that a team approach, hopefully of a multi-agency nature, be developed to provide a clear organizational structure for the research program. Research partnerships, especially among sister land-holding and land-management agencies, will increase efficiency through the pooling of resources, the identification of common problems created by adjoining land-management responsibilities, and the sharing of knowledge and skills. Initial cooperative expression could be realized through the development of integrated research designs and planning schedules (see Upham et al., this volume).

At least two additional considerations suggest the need for closely involving Forest Service cultural resource specialists. First, while research problems may be broadly applicable, their most appropriate solutions will vary with the local expression of the archaeological record. Second, the CRRAs remain the management responsibility of the affected Forest. Thus, the Forest Archaeologist has the broad-based experience and knowledge to provide (1) the necessary contextual understanding of the nature of the resource base and (2) direction in the establishment of local research and management priorities.

Potential Selection Criteria

Based on the nature of the problems being investigated and the types of data they may warrant, some CRRAs could involve those areas of forests already reserved as Research Natural Areas and Wilderness Areas. Research requirements clearly affect CRRA size, environmental variability, and cultural resource variability. For example, a study of the effect of survey unit size on the discovery of cultural resources would necessitate a CRRA that could accommodate the largest-sized survey unit. On the other hand, studies designed to investigate the nature and extent of changes that occur when cultural resources have been modified by natural processes or by surface collection (the "surface renewal" problem) should be conducted in a variety of environmental communities. Here, a relatively large CRRA or a set of small ones could satisfy the design requirement of such a study.

Examination of available cultural resource records, including Forest Service computerized site survey data files, would assist in the design of experiments to solve particular problems. For example, experiments that focus on determining the relationship between surface and subsurface remains or that evaluate various means for detecting subsurface deposits could use previously recorded information about the nature and location of specific "target" cultural resources. Based on these data, suitable CRRAs could be identified for particular experiments because they have a high potential for disclosing appropriate cultural resources.

Economics

Many of the research problems will spawn field projects that could run concurrently. CRRAs that meet all of the needs of several experiments would be most economical because their withdrawal from multiple-use status would concentrate research-dedicated areas, thereby facilitating planning for other uses of forest resources. At the same time, one or several large CRRAs would be easier to than many small CRRAs. In part, this economy is realized when the cost of modifying and reviewing modifications of the Forest Plan is considered (see below). Also, access to many widely separated or distantly located CRRAs would undoubtedly be more costly than access to a few conveniently located ones.

Designation of CRRAs

CRRAs would be designated through the Land Management Planning process. All forests in Region 3 are now managed under terms stipulated in individual Forest Plans. Setting aside an area for study that is not currently being managed for essentially non-consumptive

uses would necessitate an amendment to the Land Management Plan. In the case of the CRRA, an area of a given size in a given management area and Ranger District would be proposed as the area of study. Should the proposal potentially restrict the use of a portion of the forest to groups or individuals (e.g., range permittees, timber companies), as designation of CRRAs almost certainly would, those groups or individuals would be included in negotiations from the proposal's inception. If agreement can be reached among all concerned parties, the proposal can be treated as an insignificant amendment to the Forest Plan and approved by the Forest Supervisor. If agreement cannot be reached, or if the amendment is appealed, the designation of the CRRA may have to be considered a significant amendment and an Environmental Impact Statement (EIS) prepared.

Scheduling and Duration

We propose that CRRAs be dedicated experimental sites for at least five years. Thereafter, a few long-term projects might continue for an additional five to ten years on CRRAs that could be, depending on experimental results, reduced in size. The majority of CRRAs, however, could be withdrawn from dedicated research status and made available for other Forest uses after a minimum period of five years. The following implementation schedule is proposed:

Year 1 - **Organize partnerships** to develop research designs, operationalize problem domains, identify key personnel, and compile available data.
- **Select CRRAs** on the basis of research design requirements.

Years 2 through 4 - **Implement research** through data collection, compilation, and analysis.

Year 5 - **Report** and disseminate experimental findings and make recommendations to the Forest Service.

In view of the prioritized research problems enumerated above and the proposed implementation of research activities, at least three alternative scheduling modes or "scenarios" should be considered:

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(A) Priority #1 Priority #2 Priority #3
    |--------->| |--------->| |--------->|

(B) Priority #1
    |--------->|

          Priority #2
          |--------->|

                Priority #3
                |--------->|

(C) Priority #1
    |--------->|

    Priority #2
    |--------->|

    Priority #3
    |--------->|
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RESEARCH ORGANIZATION

In executing the proposed research program, a partnership approach would improve long-term effectiveness and coordination. Such partnerships might be arranged among land-managing agencies, especially where lands are contiguous and management needs are similar. Individuals and groups representing the private sector could be encouraged to provide funds or services for research that are appropriate to their interests. University or museum partnerships, built perhaps on the National Park Service Cooperative Park Service Unit (CPSU) model, would be especially important in providing a broad range of skills, knowledge, and experience to the research program. In such partnerships, cooperative planning, resource pooling, and information sharing would contribute to increased research effectiveness.

In promoting and structuring these partnerships for planning and executing the proposed research, the Forest Service should be fairly aggressive in assuming a lead role. Potential partners should be "sold" on the advantages of comparable and reliable information for management, and on the concept that cooperative arrangements produce good value for the investment. Along these lines, some effort should also be directed toward minimizing interagency administrative and regulatory redundancies, and generally smoothing the bureaucratic path for cooperative archaeological research activities.

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The Need for an Integrated Approach in the Use of Automated Information Systems for Archeological Predictive Modeling[1]

Mark A. Calamia[2]

Abstract.--The use of computerized information systems for cultural resource management has great potential when used in an integrated fashion. Specifically, data base management systems, geographic information systems, remote sensing techniques, and exploratory data analysis methods, when used in concert, provide a powerful package of analytical tools useful in predictive modeling studies.

To manage cultural resources effectively for large parcels of land, the U.S.Forest Service requires the ability to control, access, and manipulate appropriate classes of data. In addition, these data need to be consolidated for forest management planning. Forest Service managers need access to information concerning the current status of cultural resources and any activities that could affect this status.

In many forests, cultural resource studies have contributed a substantial quantity of data about the nature and distribution of cultural resources. With the accumulation of large data sets, it becomes increasingly difficult to properly maintain, control, and evaluate these data using manual methods.

The accumulated data include descriptive information on archeological properties such as cultural/temporal affiliation, assemblages, environmental context, provenience, and management recommendations. Another type of accumulating data involves information pertaining to the location of cultural resource inventories, defining areas which have been searched for sites, and survey intensity. Areas where sites occur, as well as where they do not occur, are found in this type of information. The environmental data class is yet another major source of accumulating information which most forests have easy access to. Finally, there is forest management and administrative information relating to current and projected undertakings such as timber sales or land development and construction projects.

A study performed for USFS Region 8 (Parker et al. 1986) noted that several needs must be met to enhance the overall quality of cultural resource data. These include: (1)improved control of and access to inventory data; (2)a data base designed for the merging of these data with survey and environmental data for use in predictive models; and (3)use of Geographic Information Systems (GIS) technology for analysis and display of environmental and cultural resource information to build predictive models.

This paper focuses on the use of automated information systems and analytical techniques for satisfying these needs. This approach was first espoused by the Arkansas Archeological Survey (Parker et al. 1986; Limp et al. 1987; Limp 1987a; Farley 1987). Much of the information presented in this paper has been summarized from their work and others.

First, a general discussion is presented of the complex nature of cultural resources, which necessitates the use of sophisticated techniques for understanding their patterning and relationships. The next section examines the use of four types of automated information systems and techniques which are proving useful for settlement pattern analysis, predictive modeling, and site discovery. These automated systems include data base management, geographic information systems, remote sensing imagery, and exploratory data analysis (Limp 1987a). Next, a rationale is presented for the use of computerized systems for meeting managerial and research needs. Finally, conclusions are drawn which point to the need to use integrated technologies for predictive modeling to satisfy Forest Service management and research requirements.

Automated Information System Needs

In order for the management of land resources to be successful, the distribution of and interrelationships among natural and cultural resources, and the manner in which these change through time and space, need to be understood. This is made possible through the discovery of regularities or patterns in multidimensional relationships. The process whereby meaningful patterns are recognized in complex data sets is greatly facilitated by the use of automated information systems.

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[1] Paper prepared for the Forest Service Cultural Resources Research Symposium, May 2-6, 1988, Grand Canyon, Arizona.

[2] Mark Calamia is an archeologist with the Bureau of Land Management, Carlsbad, New Mexico.

The distribution of archeological resources is the result of the interaction of a variety of natural and cultural variables. As such, the data can only be examined properly in a multivariate framework. Basic requirements for such an approach are to maintain a diverse variety of data relationships in an accessible and easily controlled format, and the capability to manipulate and quantify these associations to produce useful results. Automated information systems when used in concert to meet these requirements include data base management (Martin 1977, 1983), geographic information systems analysis (Berry 1986), remote sensing imagery analysis (Limp 1987a), and exploratory data analysis (Chambers et al. 1983).

Although these tools have been used successfully in various analytical efforts, these have usually focused on the use of a single form of automated system (Parker et al. 1985, Kvamme 1985a, 1985b). A recommendation will be made below for a structured program of analysis in which the individual technologies are used in a complementary way so as to be useful for predictive modeling. In this manner, it will be possible to increase our understanding of the nature, distribution, and significance of the resource base.

Four Types of Automated Information Systems and Techniques Useful for Cultural Resource Management

These systems are structured in such a manner as to assist in the organization of information while keeping data in a format which allows for quick retrieval and use. Types of DBM systems include network, hierarchical, and relational models. Each of these has its advantages and disadvantages (Parker et al. 1985: 100-107; Limp et al. 1987:19-24). All data base management systems, however, have certain attributes in common, (Farley 1987):

1. mechanisms for data entry and retrieval;
2. information storage in nominal, ordinal, and interval scales, and alphanumeric text-based data;
3. capabilities of associating diverse information through the use of keys or pointers;
4. limited quantatative capabilities; and
5. capability to import and export data through a universal format like ASCII.

These systems usually do not prove useful for managing multidimensional data, such as that required for predictive modeling, when the logical interlinkages are not known or evident. However, a DBM system which can aid in solving several closely related problems is better suited for revealing potential patterns or anomalies between data sets. A relational-type data base structure is considered best for managing multivariate data which must be linked and accessed in a variety of ways. This structure consists of a series of two-dimensional tables where each record (row) contains all the attributes or variables associated with a single object or event and each column is a group of data values relevant to a single object, event, or place. The records among different tables or files are linked to each other through the use of common identifiers which appear on each record (Parker et al. 1985:108-110). In this way, the relationships between records can be specified at retrieval time. This is accomplished by matching attribute values between different files. Thus, related records can be easily found.

Parker et al. (1985:94) have recommended that a "top-down theoretical orientation" be employed when designing DBM systems for archeological applications. In this type of approach the variables and associated relationships relevant to a specific research problem can be thoroughly defined and modeled prior to any program development.

Items about which data can be collected have been termed entities and the properties of entities which define them consist of attributes, variables, or data categories (Parker et al. 1985). For successful cultural resource management applications, a DBM system must include three entity types: (1)the archeological site; (2)cultural resource investigation; and (3)bibliographic citation. The archeological site entity should contain a variety of attributes dealing with site identification and locational information, description or technical data, managerial considerations, environmental factors, and notes. The cultural resource investigation entity must contain attribute information on the inventories themselves and notes. Finally, the bibliographic citation entity requires identification, content, and note attributes. The attributes themselves and their organization and manipulation for predictive modeling are beyond the scope of this paper. (See Parker et al. [1986] or Limp [1987a] for a full discussion of this process).

Data base management systems can provide accurate inventory information of existing cultural resource properties and some limited data on various environmental variables, e.g., soil associations or topographic position (Hillard and Riggs 1986). However, they do not have the capability to retain information on non-sites (those locations which do not contain archeological properties). In addition, they cannot maintain detailed data in a format that can be easily used to identify those dimensions or combinations of dimensions within the natural environment that may have influenced the locating of sites in particular areas (Farley 1987). Thus, data base technology alone cannot answer questions such as, "did groups having a farming economy always locate themselves in proximity to arable and and water or did elevation, slope, and vegetation play an important part in the settlement patterns of hunting and gathering peoples in a specific region?"

Questions such as these require the accumulation of extensive environmental information. This modeling requires the examination of multivariate data so as to understand the association between the presence or absence of archaeological properties and the co-occurrence of one or more dimensions of the natural environment. For example, how many sites are located on geologic surface unit x, or what is the relative density of artifacts situated on south-facing slopes within 200 meters of third order streams? Information of this type can be used for making predictive

statements which can potentially aid in explaining the mechanisms responsible for site location. At the same time, this information allows managers to direct ground-level surveys to those areas which are more likely to contain sites. One special type of database management system capable of generating information useful for modeling is a geographic information system.

Geographic Information Systems (GIS)

A geographic information system is a computer-based means for assembling, organizing, analyzing, storing, and displaying varied forms of data corresponding to specific geographical areas, with the spatial locations forming the basis of the system (Hansen 1983; Tomlinson 1984). Almost all types of geographically distributed information may be encoded in an automated-compatible form. Automated systems can extract geographic information from digital geographic databases, manipulate the data, derive new data, and perform analysis in a number of research and management contexts. Thus, GIS can be used in the analysis, interpretation, and problem- solving aspects of research of spatiallyoriented phenomena and processes.

These systems add a spatial dimension to data stored from USGS 7.5 minute or 15 minute quadrangles. This information is stored in a series of separate layers or themes which can be examined, manipulated, or compared quantitatively using a variety of methods. To illustrate, a GIS might contain data layers for archeological surveys (polygon data), archeological sites (point data), road networks and hydrology (vector data), surface geology or soils associations (polygon data), and elevation (vector). When these data are properly formatted, the GIS can rapidly identified points or areas which have common sets of attribute values. GIS technology depends heavily on the visual transmission of data through sophisticated graphic images to summarize univariate, bivariate, and multivariate distributions across space in the form of a displayed map. This capabiltiy allows the archeologist rapidly to explore a number of relationships which might otherwise go unnoticed. In addition, a cell-based GIS (see below) is uniquely suited to applications directed towards quantitative analysis and the development of predictive statements (Kvamme 1985a, 1985b, 1986). Using a GIS, many reports, coincidence tabulations, simple statistics, and proximity types of analysis can be conducted, thereby creating the basis for more sophisticated quantitative techniques.

There are two (basic) types of GIS: cellbased and vector-based. In a cell-based GIS, also called raster-based, the area of examination is subdivided into a regular grid of rectangles. These cells, generally squares of equal area, are contiguous. Data are recorded by overlaying this grid of cells on maps of the area and recording a series of data values for each cell. In a vector-based GIS, the maps of the area are encoded as a series of points, lines, and polygons representing respectively, point features (such as small archaeological sites), linear features (such as roads or streams), and area features (such as soil types or lakes). The lines and polygons are represented as a series of lines joining points whose coordinates are recorded. The advantages and disadvantages of both of these types of GIS are discussed elsewhere (Kvamme 1985b; Parker et al. 1986). For purposes of predictive modeling, cellbased GIS must be used (Kvamme 1985a, 1985b, 1986).

The GIS requires a variety of hardware and software components. Other than standard computer elements, typical GIS hardware includes the following equipment (Parker et al. 1986; Dangermond 1983):

1. Digitizer: An optical or electromechanical device used to convert map information to digital x-y coordinates suitable for computer processing.
2. Storage Devices: Relatively large hard disk systems and tape drives are necessary because geographic information requires considerable storage space.
3. Graphics Display Devices: Results of the GIS analysis are best presented in multicolor output devices. In general, both a cathode ray tube (CRT) and some form of hard copy output device are necessary.

GIS software requires these basic elements:

1. Map Development: Specialized software is needed to transform raw digitized input into useful GIS data functions and includes such capabilities as data editing and mathematical transformation. The software must be able to georeference data correctly and to register multiple data layers. Georeferencing means that correct location information is associated with the computer data. Registration means that locations in each map layer occur in the same correct relationships to each other from map layer to map layer.
2. Data Retrieval and Analysis: Various modules are required to allow the analysis of the data. Important capabilities include combining information from two or more map layers into a new, third map and comparing the distribution of values in one map layer to another.
3. Display: Special software is needed to convert the results of the retrieval and analysis to a form which can be presented on the display devices.

Parker et al. (1986) have recommended a set of GIS functions or commands which should be considered for cultural resource management. These functions are shown in table 1., Item 1-31 and 38-40 characterize a good GIS (American Farm Trust 1985; Tomlinson and Boyle 1981). Items 32-37 are quantitative functions necessary for effective predictive modeling (Kvamme 1985a, 1985b; Kohler and Parker 1986). Items 32-36 may be obtained internally in some GIS or externally by means of exporting the data to a statistical software package, such as SPSS, in a format compatible to the software (item 37). For purposes of predictive modeling analysis, the GIS must be capable of exporting data in tuples. That is to say, for any given set of cell locations, the data present in each comparable cell in each map theme should be output. Once the data are organized in this manner,

Table 1.--GIS functions useful for cultural resource management.

Data Entry

(1) Entry of raster (grid cell) data via digitizer
(2) Use standard data sources/formats
  a. USGM DEM
  b. DMA DEM
  c. USGS DLG
  d. MSS/TM Band sequential imagery
  e. MSS/TM Band interleaved imagery
  f. Arc-node
(3) Georeference data not already in coordinate system
(4) Register map data to standard coordinate systems
  a. UTM
  b. State Plane Coordinates
  c. Lat/Long
  d. Other projections
(5) Scanner input with automatic polygon and/or arc-node generation

Editing/Updating

(6) Automatic error detection/node snapping
(7) Interactive editing/updating of data
(8) Edge matching

Data Retrieval and Analysis

(9) Convert polygon/arc-node data to raster
(10) Sort attributes based on value
(11) Locate attributes in specific geographic area
(12) Detect edges
(13) Calculate distance from point to point
(14) Calculate distance along linear feature
(15) Summarize attributes by cell
(16) Compute statistics by collection of cells
(17) Compute statistics by interactively entered area
(18) Conduct nearest neighbor search
(19) Conduct proximity search
(20) Summarize points within area/polygon
(21) Calculate slope from DEM
(22) Calculate aspect from DEM
(23) Define watershed boundaries from DEM
(24) Selectively assign weights to categories
(25) Compute number of acres/other units within a specified area
(26) Change size of grid cells
(27) Perform map layer coincidence
(28) Perform map layer exclusion
(29) Perform map layer union
(30) Perform map layer multiple exculsion
(31) Perform map layer multiple weighting

Statistical/Quantitative Analyses

(32) Calculate means/mode and standard deviation for map layer or subsets
(33) Cross tabulations
(34) Chi-square expected vs observed
(35) Linear/logistic regression
(36) Classification (parallel-piped maximum likelihood, etc.)
(37) Output tuple data for multiple map layers in exportable format for input to statistical software

Display

(38) Output hardcopy at field usable scale (i.e. 1:24000, 1:12500)
(39) Output hardcopy at variety of scales with automatic pruning
(40) Output cartographic quality materials

Source: Parker et al. 1986

a large variety of sophisticated statistical operations can be initiated. It should be noted that spatial autocorrelation should be taken into account in such analysis (Rose and Altschul 1986).

Many varieties of GIS data are available from several federal and state agencies in digital form. Some data such as USGS Digital Elevation Models or Digital Line Graphs are usually already georeferenced. Other data such as soil associations or archeological surveys may have to be digitized from maps or mylar overlays.

A number of data layers or themes can be useful for predictive modeling. The data are in primary and secondary (derived) layers. Elevation is an example of a primary layer, while both slope and aspect can be derived from the elevation data by special operations. These are considered secondary layers. Other examples of primary layers relevant to a cultural resources GIS might include stream locations, distance to streams, surface geology, physiography, vegetation, location of archeological site types, areas of archeological survey, road locations, distance to roads, ranger district boundaries, planning unit boundaries, compartment boundaries, and stand boundaries (Parker et al. 1986; Kvamme 1985b).

An important point to bear in mind is that most of the environmental and administrative data needed for predictive modeling studies are the same data used by many other Forest Service specialties. Thus, only the cultural resource site and survey layers need to be obtained for implementation of a cultural resources GIS. The scale or resolution of the data needed, which includes cell size among other considerations, is beyond the scope of this presentation (See Kvamme 1985b; Parker et al. 1986; and Limp et al. 1987 for details on cell size selection).

The cost of a GIS system varies depending upon the level of sophistication and storage capacity. In addition, hardware and software specifications and costs change rapidly. Several common GIS costs are compared in table 2. These are only suggested costs and reasonable estimates as of 1986. The estimates assume that the complete system is purchased.

There are five separate stages associated with the development of a GIS data base for predictive modeling. These include variable identification and classification, identification of data sources, map preparation, data acquisition, and data editing and cleaning. For each stage, several cost-benefit decisions must be made using fiscal and technological criteria as related to the

Table 2.--System costs (in thousands of dollars).

ERDAS	
IBM PC AT with hard disk and tape system	
Plotter	
Digitizer	
Graphics boards and display	
	25 - 50
Software	20 - 50
System Total	40 - 100
MOSS/MAPS	
Data General MV 4000	
Plotter	
Graphic display	
Digitizer	
	80 - 100
Software	0 - 0
System Total	80 - 100
GRASS	
MASSCOMP 5000 Series	
Plotter	
Graphic Display	
Digitizer	
	50 - 100
Software	0 - 0
System Total	50 - 100
ARC/INFO	
Data General 4000	
Plotter	
Graphics Display	
Digitizer	
	80 - 100
Software	75 - 150
System Total	155 - 250

Source: Parker et al. 1986

anticipated requirements of the GIS. (See Parker et al. 1986:135-158 for an excellent discussion of these database development stages.)

Remote Sensing Imagery (RSI)

Remote sensing involves the acquisition of data about physical objects and the environment through a systematic process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy. Common remote sensing methods are photographic, aerial and ground based photography, and airborne or satellite multispectral scanner products. Archeologists have made use of these methods in a variety of applications designed for locational analysis and prediction. (See Ebert [1986] for an overview of archeological studies involving remote sensing methods).

Archeologists who have used remote sensing methods for predictive modeling agree that much work is still to be done if remote sensing imagery is to be effectively used in archeological research and management. The majority of the earlier studies focused on the application of digital image processing to archeological site discovery. Today, more fundamental questions have been raised regarding what we expect the spectral and spatial properties or signatures of archeological remains to be. The methods used to evaluate such techniques need to be considered with respect to this information. The physical properties of sites and their spectral consequences are currently the focus of remote sensing studies involving the use of multispectral scanners. It should be remembered that archeological sites may be extremely difficult to classify using multispectral imagery. In addition, even within a given site there may be significant variability (Limp 1987a).

Multispectral scanners record reflected and/or emitted radiation in the ultraviolet, visible, infarared, and microwave bands of the electromagnetic spectrum. For sensors to identify successfully archeological sites, one or more physical properties must be present that emit or reflect measurable radiation that can quantitatively be discriminated from radiation of non-archeological locations. Limp notes that, "...this discrimination may result from unique spectral properties of archeological sites or to the contrast between the archeological site and its setting, either in spectral character or spatial patterning." (Limp 1987a)

Physical properties present at some archeological sites may include phosphateenriched soils, organically-enriched soils, differential soil compaction, micro- and macro-relief variation, and regularity in edges or patterning in soil/vegetation. However, these properties are not usually directly detectable by multispectral scanners. Instead, a set of "proxy" biophysical properties which are closely interlinked with these physical properties are potentially capable of measurement with appropriate multispectral scanners. These "proxy" biophysical properties may include soil temperature, vegetation type, vegetation vigor, and moisture retention (Limp 1987a). Obviously, certain vegetative settings in forests will be more amenable to this type of analysis than others.

As alluded to above, more accurate classification is required for accurately locating sites. But even if it is highly accurate, remote-sensing imagery alone can only aid in locating sites. In terms of research and management, it is essential to increase our understanding of the processes which generated the observed patterns. In order to improve our accuracy and to address processual issues, remotely-sensed information needs to be integrated into a comprehensive automated data processing environment. This environment should include alphanumeric attribute information on archeological sites, surveys, and projects, cultural resource spatial and environmental data in a geographic information system, and software for exploratory data analysis (EDA) to assist in ascertaining complex multivariate patterning. Researchers including Sever (1983), Ingles et al. (1984), Kvamme (1985a), and Lafferty et al. (1981), have

suggested that remotely sensed data could best be used in a GIS environment. Some archeological investigations have successfully utilized remote sensed imagery in a GIS context (Wells et al. 1981; Custer et al. 1983, 1984, 1986; Holmer 1986, Limp 1987b). Effective digitizing options, useful cell sizes, and digital data sources were among the essential requirements for these studies. Hardware components must also be capable of handling large data files and producing high resolution diplays.

Recent work by such groups as the Construction Engineering Research Laboratory, the Space Remote Sensing Center, the University of Washington Statistical Laboratory, the MASSCOMP Corporation, and the Arkansas Archeological Survey have led to the development of an integrated system which is widely available at relatively low cost. (See Limp 1987a; Limp et al. 1987 for details on the structure of this system.)

Exploratory Data Analysis (EDA)

Data bases and geographic information systems are capable of providing qualitative and quantitative information on the character and spatial distribution of resources. However, most of these systems do not possess the functions necessary rigorously to investigate the underlying distribution of the raw data. In addition, they lack the sophistication necessary to examine these distributions so that basic assumptions of complex statistical methods are not violated. EDA software must be used to meet these requirements.

EDA increases our understanding of the distribution of individual variables and the multivariate relationships which may exist between variables. This is made possible through the use of boxplots, histograms, crossplots, scattergrams, etc. In this manner, it is possible to ascertain better whether or not the data conform to the distributional assumptions of more robust statistical methods. As suggested above, the data from DBM systems can be integrated with the data from a GIS and/or with remotelysensed digital data, with the resulting information examined using EDA techniques. These EDA techniques are available at a relatively low cost in the form of various statistical packages or "canned" programs (Limp et al. 1987; Limp 1987a; Parker et al. 1986; Farley 1987).

A Rationale for the Use of Computerized Systems for Cultural Resource Management

The Forest Service is now engaged in the performance of many intensive archeological surveys for roads, timber cuts, land sales, and other projects. Because of this inventory work, a substantial corpus of site and non-site data is becoming available. What is currently lacking in many forests is the capability easily to access these data and combine them with environmental data for particular areas of need.

In the past, potentially useful environmental data have been available from a variety of data sources, usually in the form of maps. However, these sources do not allow for easy comparisons with cultural resource data. In particular, they do not permit the necessary multivariate considerations of two or more data sources necessary for predictive modeling.

As shown in this paper, computerized systems are now available that have the multivariate capabilities to manipulate and analyze complex spatial data. Geographic Information Systems, in particular, are similar to other automated DBM systems in that they present a generalized, automated structure for the entry, storage, and retrieval of geographic data. Although they are similar to other DBM systems, they are made more complex by the added spatial component of the data and by substantial size (Calkins 1984). Another major difference is that GIS data bases require large investments of time for data acquisition in order thoroughly to represent the biophysical characteristics of particular areas.

In 1985, Tomlinson Associates, Inc. initiated a workload and functional analysis to ascertain which information products would be most useful for Forest Service managers. They also identified the data requirements for producing these products (Tomlinson Associates, Inc. 1985; n.d.). The intention of the Forest Service, in time, is to create Forest-level digital geographical data bases of its natural resource data in a form that will allow for easy updating, the performance of various digital analyses, and the generation of results to assist Forest managers in land administration.

From this study, Tomlinson Associates, Inc. was able to determine the present and nearterm information needed for effective management of the land base and its natural resources within a specified field unit. The results describe the spatial data handling processes and workload over time to produce information products required by forest resource managers to effect daily management decisions. As far as technological requirements were concerned, they identified archeological distribution and prediction maps and lists of cultural resources as the information products required. These data products are needed to answer questions concerning the prediction of likely locations for prehistoric sites, the determination of historical settlement patterns, and the general pattern of artifact density.

Accessibility to various forms of environmental data has increased substantially in recent years through the development of digitized data from various state and federal sources, e.g., Soil Conservation Service, USGS, and land and survey offices. Table 3 shows the suite of environmental data now available in digital format. With the use of geo-based software, these data sets can now be merged with archeological site and survey data to produce predictive models which are useful in planning for general land management or for specific projects.

Conclusions

As mentioned above, the leading proponent for the integration of the various automated techniques for cultural resource management on public lands is the Arkansas Archeological Survey (Parker et al. 1986, Limp et al. 1987). The views presented here

Table 3.--Data sources for developing a cultural resource management GIS.

Category	Source	Type	Resolution	Scale
Elevation	Defense Mapping Agency Aerospace Center	Raster	90 m	1:200,000
	National Cartographic Information Center	Raster	30 m	1:24,000
Landuse/Landcover	National Cartographic Information Center	Vector	NA	1:100,000
		Vector	NA	1:250,000
		Raster	200 m	NA
Political/Census Boundaries	National Cartographic Information Center	Vector	NA	1:24,000
		Vector	NA	1:100,000
		Vector	NA	1:250,000
	Bureau of Census	Variable	NA	1:24,000
		Variable	NA	1:100,000
		Variable	NA	1:1,000,000
Hydrologic Units (Watershed)	National Cartographic Information Center	Vector	NA	1:100,000
		Vector	NA	1:250,000
		Raster	200 m	NA
Transportation	National Cartographic Information Center	Vector	NA	1:24,000
		Vector	NA	1:100,000
		Vector	NA	1:200,000
Hydrographic (Streams and Waterbodies)	National Cartographic Information Center	Vector	NA	1:24,000
		Vector	NA	1:100,000
		Vector	NA	1:200,000
Soils	Soil Conservation Service	Vector	NA	1:24,000
		Raster	4 hectare cells	NA
Geology	National Cartographic Data Center	Variable	NA	Varied
Satellite Imagery	SPOT Image Corp.	Raster	10 m (panchromatic)	NA
		Raster	20 m (panchromatic)	NA
	Earth Observation Satellite Co. (EROSAT)	Raster	80 m (MSS, RBV)	NA
		Raster	30 m (TM)	NA
MSS Airborn	Environmental Protection Agency	Raster	Variable (MSS)	NA
	National Space Technology Laboratory	Raster	Variable (MSS)	NA

Source: Johnson and Goran 1985

are based largely on their observations and recommendations in using the various technologies discussed for predictive modeling applications. The Arkansas Archeological Survey studies have utilized the integration of several types of computerized data bases for archeological investigations.

Automated information systems are suited to meeting the needs of short-term projects, long-range planning efforts, and the scientific investigation of various cultural resource phenomena. Problem-solving is usually associated with short-term management in which managers try to achieve a particular goal while remaining in compliance. In the case of Forest management, a project such as road construction needs to be completed or a logging area needs to be identified and used, and a Forest manager simply wants to resolve the problems as expeditiously as possible. The implementation of a structured automated program involving data acquisition, organization, and analysis will provide Forest managers with the information needed to make informed decisions for program implementation. Through time the models produced by such a structured program will become more refined with the accumulation of additional data, thereby insuring that the process will become more efficient and useful.

Once predictive models are developed and subsequent iterative refinements are made of the modeling process itself, an environment conducive to a structured automated program for cultural resource management can develop. Farley (1987) points out that once the initial models are developed, they can serve as the basis for a long term planning strategy. This strategy can be developed as a guide to projecting the nature, density, and distribution of resources likely to be present in land areas of varying sizes and shapes. A potential benefit of such planning is refinement in estimates of inventory costs, personnel needs, and schedules. Another benefit is the ability to perform planning specifically related to cultural resources. Because this integrated structured program involves the use of DBM, GIS, RSI, and EDA, a requirement exists for the systematic collection and analysis of data to develop a standardized body ofinformation. In this manner a comparative basis for resource information is created. This, in turn, enables the development of rationale criteria for implementing preservation measures.

Finally, the application of an integrated information system program to the management of cultural resources greatly aids in the building of models necessary for the explanation of various archeological phenomena such as settlement patterns, land use, and adaptive strategies. Because these automated tools help to increase our understanding of the underlying processes responsible for that distribution, the ability to focus on research problems is enhanced.

It should be remembered that a technology cannot be a solution to all resource management problems; however, by effectively integrating "high tech" tools for predictive modeling, the Forest Service can only enhance the management and appreciation of its cultural resources.

Acknowledgement

I would like to thank Dr. W. Frederick Limp for providing me with some of the sources and general information used to prepare this paper.

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(The remainder of Mark Calamia's literature citations appear on page 214.)

Cultural Resources on National Forests: New Products for New Markets[1]

Linda B. Kelley[2]

Until recently, cultural resources interpretation on national forests has received little attention. Theoretical and methodological issues and concerns are outlined and a creative approach to cultural resources interpretation, framed within marketing concepts, is proposed. A recurrent theme is that the public to be served must be understood in order to produce a quality product.

INTRODUCTION

Cultural resources managers on national forests are responsible not only for the material remains of this nation's heritage, but for the oral traditions associated with it as well. We have a heritage to tell. Our success is dependent upon leadership aimed at strengthening our public presence and reinforcing heritage values through creative interpretive efforts.

Cultural resources, the material remains of past human activity, are significant to our national heritage for the knowledge they provide of the past regarding behavior and interactions as integral parts of changing cultural and natural systems. They also provide such indirect benefits as education, training, public enjoyment and economic enhancement opportunities.

Our national heritage is recovered and interpreted through the process of archeology. Professional archeologists have suggested that archeology provides a closeness to one's past and present, its techniques are fascinating, and the act of discovery stimulates a vicarious experience (Fritz 1973). Additionally, it is said (MacLeod 1977) to be a public recreational resource, an artistic adventure, a detective mystery, and a focus of thousands of human needs and interests.

In spite of these projected social and individual values, public opinion regarding archeology, and therefore, cultural resources, is mixed. For instance, the public believes the money it has invested has yielded little in return. Consequently, the archeologist has been popularized as a slightly anachronistic, doddering pith-helmeted, bearded professor, someone who serves as an intermediary between the quick and the dead (Fritz 1973; Sanday 1976), or, recently, as a swash-buckling adventurer. Such mixed opinions are attributable to an apparent lack of opportunities for public participation in the archeological process. One means of affecting participatory opportunities is effective cultural resources interpretation which not only informs, but also imparts to the general public its projected values.

In developing a concept of what constitutes effective cultural resources interpretation, elements from marketing have been employed. Marketing provides a framework in which interpretation may be designed in terms of its product, place, promotion, and price. Products, defined by their purpose and developed to provide a satisfactory experience, will be discussed in this paper. The objective is the creation of interpretive products which will foster public cooperation, our first line of defense in the conservation of this nation's heritage.

CULTURAL RESOURCES PRODUCTS

It has been argued (Gumperz 1976) that participation in any decision-making process that affects the quality of life is required by modern society, and that opening communication channels is is an important factor in maintaining quality and continuity in urban life. A communication crisis, characterized as a widespread misunderstanding, has been identified in archeology. One reason for this misunderstanding is failure on the part of professionals to recognize that heritage and history are not conceptual vehicles; the public cannot identify an event unless they are at the place where the event occurred. At the same time, the public has become more aware of cultural resources as the result of population growth and its encroachment on sites, and increased leisure time and its attendant travel.

Alleviation of this misunderstanding by

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[1] Paper presented at the Forest Service Cultural Resources Research Symposium [Grand Canyon, May 1-6, 1988].

[2] Linda B. Kelley is Assistant Archeologist, Tonto National Forest, Phoenix.

opening communication channels has been frequently discussed during the past several years. At first, the focus was on educating the profession in the need to communicate with the public, based on the assumption that without effective communication it is not possible to influence a person's ideas or his approach to a subject. While positively influencing opinion remains a primary concern, the current focus is on educating the public through responsible communication of our cultural heritage by every possible means (Gumerman 1982).

One process by which responsible communication can be accomplished is cultural resources interpretation. This process is complex, beginning with the attempt to understand the public being served. In particular, those being served must be accepted as a source of information, and their experiences and idiosyncracies must be considered.

That portion of the general public with which we are concerned is user populations comprised primarily of national forest recreationists. These users choose activities which are consistent with their basic outlook on resources, the environment, and quality of life (Jackson 1986). The satisfaction they derive from recreation activities depends on the uniqueness of the experience, their expectations, and practical matters such as distance and accessibility.

Forest recreationists can be further segmented by number and type of users, use patterns, site preferences, and user characteristics. User characteristics which define especially meaningful segments are quantifiable differences in age, education level, interest, and goals to be achieved in recreational activities. One segment identifiable through analysis of use patterns is non-users. Barriers to use require further research, but socioeconomic factors and individual perceptions (e.g., is it for me?) particularly warrant consideration in the design of interpretive products.

Evaluation of the potential for use of specific resources by any population segment aids in the identification of marketing targets, those users and needs for which cultural resources interpretive products can be designed, promoted, and delivered. Throughout product development, it is important to recognize that users generally participate as members of social groups, and that such groups significantly influence individual values, attitudes, preferences, and perceptions. Indeed, the potential for the social group to function as an effective transmitter of interpretive messages should be used to advantage (Field and Wagar 1984).

The Setting

Within museum philosophy, the setting in which interpretation occurs is conceived of as a stage (Grinder and McCoy 1985); the production presented thereon allows the public freedom of movement, thought, and timing to interpret in its own terms the representations made. Cultural resources settings can also be conceived of as stages; consequently, some attributes of such settings may be derived from theatrical contexts, including size, visibility, line, color, costume, and script.[3] Additional attributes of cultural resources settings are site history, who the archeologists are and the nature of their work, and who is making the presentation. In a successful performance, all of these attributes are functionally arranged to focus attention and to complement basic elements of good public presentation, including communication (the relationship between individuals), being in role, and caring about the audience.[3]

Development of an awareness of audience/user needs is a critical element in the creation of a setting in which public presentations of cultural resources interpretation occurs, as well as being essential in the design of quality interpretive products. Three specific needs that a setting must satisfy are those for reverence, education, and association. These are expanded to mean a personal experience with something out of the ordinary, a place to interpret the world and to incorporate events into a search for life's meaning, and a place to socialize (Adams 1983).

Associational or social needs are self-explanatory. These will be easy to provide once user preferences regarding places have been determined. Reverential needs (experiences) are best met when a link between the public and the information being presented has been created. Several interpretive products are used to create this linkage; these are subsumed under the term "script" in this paper.

Research is necessary in order to define educational needs and to identify segments for which interpretive products may be designed. For instance, it has been observed by the tourism industry that providing educational experiences for children is currently a prime concern in vacation planning. Pending further study, it is worth suggesting that past interpretive efforts undertaken in cultural resources settings have often not produced a satisfactory experience.

Traditional functional interpretations, especially of material remains, have been cited (Frese 1960) as being at fault; they imply a realism which does not coincide with the reality of cultural resources in their original context. Consequently, a sense of neutrality is produced and any living qualities in the cultural resources setting are extinguished. To alleviate problems resulting from this neutrality, to rekindle living qualities, and to facilitate educational needs, interpretive products should be designed in such a way that they stimulate the desire to discover and

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[3] Wright, Lin. 1985. Personal conversation, Theatre Department, Arizona State University, Tempe.

then to understand. The goal of this provocative approach is to instill a sense of appreciation and generate protective feelings within the public.

The way in which attributes of a setting are arranged to meet needs, and integrated with the script, provides structure in which the public can intellectually and cognitively "buy" the past (Leone 1981). It is within this structure that the user brings life to the setting through his imagination, aided by the interpretive products and his own textbook knowledge. What he takes away are the performers' messages, effectively communicated because of the "extraordinary reality" of the setting in which they have been conveyed (Leone 1973).

A Satisfactory Experience

Rather than the simple communication of facts, the interpretive process is defined (Tilden 1967) as an educational activity undertaken to reveal meanings and relationships through the use of original objects, firsthand experience, and illustrative media. Through this activity, framed within the context of user experiences and values, an attempt is made to create understanding and excitement, and to stimulate curiosity (Alderson and Low 1976; Grater 1976; Grinder and McCoy 1985; Tilden 1967). In terms of cultural resources, the interpretive process should primarily function to distinguish between information and the image created when the public is made aware.

Interpretive images are evoked through the material remains of past human activity, which have typically been treated as passive objects of functional use. A more provocative and creative approach would be to present these remains as elements of daily living analogous to our own. Material remains become relevant to contemporary usage through interest, relationship to personal needs and experiences, and perceived psychological and physical betterment (Fritz 1978).

Information is conveyed in cultural resources interpretive settings by means of a script. "Script" encompasses all aspects of textual and verbal material associated with a particular setting, including maps, signs, labels, exhibits, storyboards, brochures/guidebooks, and oral presentations. In guidelines for creating scripts, development of a conceptual and methodological framework has been emphasized (Frese 1960; Leone 1981; Tilden 1967). Conceptual issues to be addressed are who the visitors are, why they come, and their sense of involvement, belonging, and identity with heritage (Alderson and Low 1976).

Methodological issues focus on the approach used to convey the desired information content, including compare/contrast, imagination, or thematic emphases (Grinder and McCoy 1985). Perceptual and analytical skills are sharpened as the result of similar objects being presented in a way that clarifies their differences when compare/contrast approaches are employed. It is equally important to present objects that are clearly contrastive, which aids in the understanding of similarities. Compare/contrast approaches demonstrate archeological techniques and develop skills within the participating public. In the thematic emphasis approach, an interpretive product is designed around a single or common theme with a clearly-defined learning goal. This approach, other than its use in the broadest sense to develop a key message for a setting, contradicts the provocative format proposed herein.

Children respond positively when stimulation of the imagination is used as an approach since they are generally not bound by adult conventions (Grinder and McCoy 1985). While this approach may be more difficult in adult application, the role of interpretation has been cited as the provocation of a sense of curiosity and excitement. One method for achieving this, in terms of script, is to create a story which focuses on people within the context of the setting. By putting people in the setting, a relationship with the public is established which allows for the use of the imagination regarding elements of human nature and daily living.[3]

Once a framework is established, interpretive information should be presented as a discussion between the questioning public and the inhabitants of the area (Frese 1960). Indeed, it has been argued (Leone 1981) that the past cannot be represented in lifelike fashion if the presentation is one-sided. This discussion between past and present must be based on what the target segment needs. Brief, inspiring, and luring terms should be used since the public will generally be standing. An element of movement or action which conveys that those who have lived in a setting could return at any moment should be incorporated in the composition (Alderson and Low 1976; Tilden 1967). It is proposed that interpretive products designed following these guidelines will be in contrast to those most typically experienced: memorized dogma repeated in a setting which has been stripped clean of any evidence of life, present or past, leaving the visitor with a feeling he may look but not touch.[4]

To ensure that interpretive objectives are met, a set of guiding principles aimed at enhancing user experiences in recreational/leisure settings is offered (cf. Field and Wagar 1984:13). These are that (1) users and leisure settings are diverse and a variety of approaches will be required; (2) a relaxed and enjoyable atmosphere is anticipated; (3) interpretive information must be rewarding; (4) interpretive information must be readily understood; and (5) feedback is essential. In addition, principles particular to cultural resources interpretation have been identified (Hoffman

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[4]Pilles, P. J., Jr. and D. Freeman. 1981. An interpretive concept for Nuvakwewtaqa Ruins in Chavez Pass. Ms. on file, Coconino National Forest, Flagstaff.

1984). These are that presentations must be positive and appeal to curiosity or self-interest, and language must be clear, concise, contemporary, and non-offensive. Our interpretive goal is to create a link between the user and the information being presented. Our purpose is to assure that the user understands what is being done, what the objectives and the implications of the activity are, and what is expected from him (Warner 1978). Through the use of creative methodological and theoretical applications which identify and address public issues and concerns this can be achieved.

MARKETING CULTURAL RESOURCES

Recent National Park Service and other surveys have documented increased and higher use of cultural resources sites than scenic or other recreation areas. While it is recognized that historically people have shown an interest, these observed increases emphasize that there is a market for cultural resources interpretation. In response to this demand, the Forest Service has initiated a recreation strategy aimed at meeting user needs. One part of the stated objective of this strategy is "to achieve a spirit of innovation through empowerment of USDA Forest Service people to take actions that move recreation into its full role."[5] The delivery of quality cultural resources interpretive products is one such action.

In order to accomplish this action, user needs must first be defined. Information required to define these needs includes data on user demands, perceptions, and values, barriers to use, and predictors of use trends and user behavior. This is part of the marketing process, a conceptual framework within which mechanisms for telling our national heritage should be developed. This framework's foundation, listening to the customer and finding out his needs and wants, is no different from that upon which effective cultural resources interpretation is built. Tools with which to assess needs and wants remain to be designed.

After these initial assessments are made, target markets can be selected. Two critical factors in this selection process are the use-potential of a given population segment (e.g., income and education levels, use patterns of free time, availability of recreation time) and geographic proximity. When targets have been selected, products can be developed. For national forest recreationists, the product is the user's experience; in this case it is the cultural resources interpretive experience.

Critical elements in product development and the assurance of a satisfactory user experience include purpose, price, place, and promotion. The purpose of cultural resources interpretation (e.g., information, orientation, entertainment, primary or secondary attraction,) and price/value relationship (e.g., worth the time, trip, effort) are directly related to the segment which has been targeted. The place at which the experience occurs is determined on the basis of its location and accessibility, and on the ambience/atmosphere of the setting. Data need to collected on what attributes constitute a high quality "place," and furthermore, how "quality" is defined for diverse sites, user groups, and activities. Ways to promote the experience and make the public aware must be developed, based on assessments of media, messages, symbols, and communication styles that are most effective in reaching out to diverse users, encouraging a conservation ethic, and controlling vandalism.

To summarize, several issues critical in the design of effective cultural resources interpretive products that require further inquiry and synthesis have been identified. In particular, a synthesis of National Park Service, tourism, museum, and outdoor recreation studies is needed. This would serve as a foundation upon which inquiry regarding local community benefits, appropriate places and levels of interpretation, effective exhibitry and promotional techniques, price/value relationships, and the types of interpretation that are accepted and understood could be conducted. Further, syntheses would aid in the development of feedback mechanisms designed to evaluate and assess cultural resources interpretive policies, actions, and products as they are implemented.

Within the context of the Forest Service's recreation strategy, we have been challenged to provide cultural resources interpretive products. The marketability of the product depends on generating interest; this can be achieved by offering a unique experience which tells an important story that captures attention. Our goal is positively to influence public opinion. This will be accomplished through leadership in exploring new technologies and alternatives for meeting the wide-ranging needs of forest users, and in creative applications which enhance public appreciation and understanding.

[5]USDA Forest Service. 1988. Chief's implementation schedule for National Recreation Strategy, dated 2/5/88.

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Bringing the Past to the People: a Research Proposal for Cultural Resources Interpretation and Education on the National Forests[1]

Anne R. Baldwin[2], Diane E. Gelburd[3], Paul Katz[4], Linda B. Kelley[5], Charles H. McCurdy[6], and Gary D. Stumpf[7]

INTRODUCTION

Within the U. S. Forest Service, a strategy has been designed to help the National Forests achieve their full potential in meeting the recreation needs of all Americans. Cultural resources interpretation has been identified as one means of meeting recreational needs. Region 3, the Southwestern Region of the Forest Service, contains a vast array of cultural resources, but little thought has been given to providing interpretive opportunities. There are no regional visitor centers dedicated to cultural resources, the potential of cultural resources to generate revenue has not been considered, and opportunities for visitor centers, special emphasis areas, and recreational facilities related to interpretation and cultural resources have not been analyzed and identified. Because Region 3's potential has not been tapped, an interagency work group was formed to identify research topics relevant to cultural resource interpretation and public education, and to create a research plan which can serve as the foundation for the full development of the interpretive potential.

The process for cultural resource interpretation occurs within the guidelines provided in Forest Service Manual Title 2300, Recreation, Wilderness, and Related Resources Management, and Chapter 2390, Interpretive Services. Seven objectives are stated for interpretive services (see Appendix A). Their focus is on gaining an appreciation and understanding of the Forest Service's role in resource conservation and management while providing recreation opportunities and facilities. Interpretive services is a management tool for use in meeting these objectives; by extension, cultural resource interpretation is also a management tool.

In light of the foregoing, the Cultural Resource Interpretation and Public Education work group defined goals for interpretive activities (taken from the Region 3 Cultural Resources Interpretive Action Plan), and assessed the status of knowledge and technology in interpretation. Based upon these goals and assessments, two broad topical research areas were identified. One is the need to compile and synthesize the existing literature specifically concerned with cultural resources public education and interpretation, and the research necessary to identify Forest user profiles, wants, and needs. The other research area involves an evaluation of each type of cultural resources public interpretive and education program currently operating in, or associated with, the Forests. A discussion of implementation strategies and cost estimates are included with each research project.

GOALS

The goals of the Region 3 Cultural Resources Interpretive Action Plan address concerns important to the the public, the Forest Service

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[1]Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2]Anne R. Baldwin is an archeologist with the Coconino National Forest, Flagsfaff, AZ.

[3]Diane E. Gelburd is the Chief Archeologist of the USDA Soil Conservation Service, Washington, DC.

[4]Paul Katz is Director of the Museum Program of the Center for American Archeology, Kampsville, IL.

[5]Linda B Kelley is Assistant Archeologist on the Tonto National Forest, Phoenix, AZ.

[6]Charles H. McCurdy is a public interpretation specialist, retired from the National Park Service, Santa Fe, NM. He resides in Santa Fe.

[7]Gary D. Stumpf is the State Archeologist of the Bureau of Land Management, Arizona State Office, Phoenix, AZ.

manager and the professional archeologist. The Forest Service will provide the visitor with a unique, meaningful, quality experience. This experience should and will include the complementary aspects of recreation and education.

The Forest Service views visitors as a diverse assortment of users who place different demands on the Forests' resources. Each user has varying degrees of interest, knowledge, and levels of expectation regarding interpretation of cultural resources.

The research proposed to support the interpretive plan will incorporate input from researchers, but also from on-the-ground personnel at all levels. It is not intended to tax the existing workload of these project managers. It will, however, have the long-term result of providing field-going personnel and line officers with supplemental information which will facilitate future project activities.

The archeologist will have at his or her disposal a body of information to enter into previously untapped sources for partnerships, eventually leading to increased awareness of our cultural heritage, and hopefully to a reduction in vandalism and a rise in a protection ethic.

Regardless of the inherent user-group differences, the Forest Service is committed in its efforts to expose each visitor to a variety of cultural resources in a variety of formats. Our goals for a productive interpretive plan are four-fold, and center on the themes of service to the public, and awareness and appreciation of cultural resources. Our goals are simply to:

- serve people by providing opportunities for diverse audiences to discover and enjoy cultural resources on Forest Service lands;

- contribute to an appreciation of our cultural heritage and its relevance to present day life and people;

- enhance recreational experiences for Forest visitors through quality interpretive programs and materials; and

- strengthen cultural resources protection through increased public awareness and understanding.

STATUS

There is no comprehensive data base or report on the "state of the art" with regard to cultural resources interpretation. Many agencies, universities, and organizations are providing public interpretation of cultural resources. However, it is difficult to obtain information on who is providing interpretation, their methods, their audience, and the effectiveness of their programs.

Currently, the National Park Service is developing a data base, called the Listing of Education in Archeological Project (LEAP) Clearinghouse, on Federal archeology public awareness activities but it does not include State, local, or private efforts.[8] This data base includes information on methods used to interpret cultural resources to the public and can, therefore, provide a framework upon which we can build.

To our knowledge, no studies have been conducted on the kinds of users interested in cultural resources. The few studies conducted on the effectiveness of cultural resources interpretive programs are site specific and not well known (Leone 1981).[9]

To develop an effective cultural resources interpretive program, much information is needed. First, we must find out who our users are and what they want. We need to establish a user characteristics profile: average age, educational level, occupation, and interests. Secondly, what is the user's perception of cultural resources and of a quality recreational experience? For example, do people perceive cultural resources as part of their heritage, an educational experience, or something useless? Thirdly, what are the Forest Service's needs and perceptions? What are our management requirements? Do we need to allocate cultural resources to different use categories? Do we need to inventory all cultural resources before we design a public interpretation and recreation program? Is there a perceived need both inside and outside the Forest Service for a cultural resources public interpretation plan? And fourthly, what is the effectiveness of various public interpretation strategies? By determining the effectiveness of signs, brochures, displays, tours, participation on excavations, and the like, one can design the best public interpretation program to meet user needs and wants.

In summary, little is currently known about cultural resources interpretation. Before the Forest Service develops an interpretation program, we must develop a comprehensive research plan to obtain information on:

1. user characteristics and needs;
2. public perception of cultural resources;
3. Forest Service management needs and perceptions; and
4. the effectiveness of various public interpretation strategies.

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[8] USDI National Park Service. 1988. Listing of Education in Archaeological Project (LEAP) Clearinghouse. Archeological Assistance Division, Washington, D.C.

[9] See also Kelley, Linda B. (Hohman). 1986. A Heritage to Tell: Public Outreach in Archaeology. MA Thesis, Department of Anthropology, Arizona State University.

RESEARCH PLAN

In the following we propose a research plan to address the problems identified above (see Appendix B for related considerations).

Research Project Priority 1: User-Needs Research

This first research project is composed of two steps. The first step is to compile, synthesize, and evaluate the available literature on user needs. These data will form a basis to develop a marketing study that will provide information, for the researcher and Forest Service management, not available in the existing literature

Step 1: Compilation, synthesis and evaluation of available literature.

Rationale.--Our concensus is that there is a body of literature that pertains to the public education and interpretation of cultural resources. However, this literature is subsumed within a wide variety of other categories, making its retrieval difficult and thus compromising its usefulness.

We recommend a research project in which the appropriate categories of literature are searched for all references to the interpretation of cultural resources undertaken for the express purpose of educating the general public. These references would then be obtained in some readable form by the researcher, assessed for content, annotated, characterized, and accessioned into a special cultural resources public education and interpretation library. Both the annotated bibliography and the reference library will provide a valuable component to the Forest Service's cultural resources management effort and will represent a unique resource for non-Forest Service researchers, interpreters, educators, and managers.

Implementation.--The mechanisms for identifying, locating, and retrieving the appropriate references are not considered here. We assume this project will be undertaken by a trained and competent researcher who will be provided with adequate and sufficient tools and resources to accomplish these tasks. Our work group discussions highlighted a series of literature and data categories containing references to cultural resources public education and interpretation. We list them below with examples of the types of appropriate reports. We emphasize that this does not represent a complete listing of potential bibliographic sources.

- outdoor recreation
- archeological site public interpretation (e.g., Kwas 1986)
- cultural resources protection (e.g., Ontario Ministry of Culture and Recreation 1976)
- public involvement with archeology[10]
- public perception of cultural resources (e.g., Texas Historical Commission 1984)
- visitor surveys
- tourism surveys and literature (e.g., Farrell with Angevin 1986).

We suggest that this research be conducted by one GS-9 Forest Service employee or equivalent. The research project will extend over a six-month period, during which time the appropriate references will be identified, obtained, analyzed, annotated, classified, and archived. We realize that all the extant literature will not be identified or obtained, hence the establishment of a time limit is appropriate. We also realize that this valuable resource must be made available for other research projects recommended by our group, and to Forest Service interpreters and managers at the earliest possible opportunity. We also strongly urge that this literature compilation and annotation project be continued as a small but ongoing activity by an appropriate Forest Service employee. We also recommend that the final disposition of this resource be the USFS Rocky Mountain Station Library, so as to be accessible for searches via the FS INFO system.

Estimated Cost: $20,000 for a six-month study.

Step 2: Marketing Studies on Forest Cultural Resources Users

Rationale.--It is anticipated that the information gathered during Step 1 will not be sufficient to develop a user profile. Therefore, Step 2 is a marketing study to obtain necessary information not available in the extant literature. Market studies help producers tailor their goods to meet the expectations of consumers. For land managers, market studies are useful tools for deciding how to reach Forest visitors with messages that can inculcate an individual sense of responsibility for leaving unharmed our nonrenewable cultural resources. These studies enable Forest Service managers to produce effective messages that lead to cost-effective allocation of Forest Service dollars and to a more certain degree of "customer satisfaction."

Implementation.--While we realize that this is not the proper forum to recommend specific operational aspects of a marketing study, we do think that multiple studies should be conducted to identify and gather sufficient information with which to base management decisions for public education and interpretation of cultural resources in the National Forests. Data should be collected on the following broad categories:

- visitor profiles, including demographic and socioeconomic data;

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[10] For example, see the periodic newsletter issued by the Institute for American Research, Tucson, AZ, titled Archaeology in Tucson.

- visitor expectation and satisfaction data; and
- visitor attitudes towards cultural resources in general, and public interpretation in particular.

Considering the fact that the Southwestern Region is environmentally variable and that studies dealing with the interaction of users and the environment have not been investigated, we recommend that the research be conducted region-wide and stratified by natural zones. Analysis of these data may provide information on what kinds of places provide the most satisfactory experiences for the widest array of visitors. Additionally, this research may enable managers to define "quality" for activities and areas, facilitate quality on-the-ground management of cultural resources, and lead to a stronger conservation ethic and reduced vandalism.

Research at the Lyndon B. Johnson National and State Historical Parks (Mills and Wegner 1985) provides useful examples of data gathered in a recreational park setting.

Estimated Cost: $50,000 for an eighteen-month study.

Research Project Priority 2: Determining the Effectiveness of Existing Public Programs

Rationale

There is considerable diversity in Forest Service cultural resources public education and interpretation programs, including on-site interpretation, outreach programs, and public participation programs. Determining the effectiveness of established public programs is an obvious mandate for research efforts.

Substantial amounts of time and money are spent each year in Region 3 on Arizona Archaeology Week activities, the Site Stewards Program, and public archaeology at sites like Elden Pueblo. Public involvement at the sites of Shoofly and Besh-ba-gowa, and volunteer programs like SWAT (Southwest Archaeological Research Team), are sponsored by State and municipal agencies, volunteer and service-oriented organizations, and individuals. These programs serve as ready-made research laboratories that provide a broad spectrum of information on education and interpretation. Other efforts are represented by brochures, videos, and displays. The success of existing efforts needs to be examined, including personnel and funding concerns, prior to expansion of existing programs or new program developments.

A program designed to research the effectiveness of existing efforts should measure changes in public attitudes toward cultural resources, the degree to which people choose to participate in historic preservation or archeological activities, trends in pothunting and other forms of cultural resource vandalism, public awareness of the values inherent in historic and archeological resources, and public satisfaction with the education and interpretation opportunities provided. The following examples are offered:

Implementation:

<u>Example 1</u>.--In particular, the effectiveness of the Site Steward program as a public outreach effort to detect and deter vandalism should be evaluated by selecting a sample of sites that are regularly monitored by Stewards and comparing them to a control group of sites with similar physical and locational characteristics. Monitoring both groups of sites semi-annually over a period of several years would provide objective, quantifiable data on program success in accomplishing what it was designed to do.

Estimated cost: $2,000 per year for a period of five years = $10,000 total.

<u>Example 2</u>.--Arizona Archaeology Week activities are designed to increase awareness of cultural resource values and influence public attitudes about historic preservation and archeology. The effectiveness of this comprehensive public awareness campaign should measure levels of public participation during the week-long activities, assess trends in vandalism observed by State and Federal agency archeologists and law enforcement officials, and solicit, through questionnaires, public attitudes on the importance of preserving cultural properties. Research should compare the various types of media, messages, and communication styles used in relation to how effective they are in encouraging a conservation ethic. A starting point for research on this program is already available in annual reports prepared by the Arizona State Historic Preservation Office. These reports summarize basic information on all activities sponsored statewide.[11]

Estimated cost: $8,000 per year for a period of five years = $40,000 total.

<u>Example 3</u>.--The effectiveness of participatory archeology programs, such as those at Elden Pueblo, Shoofly Ruin, and Besh-Ba-Gowah, should be evaluated by charting participation levels over a period of years and by asking participants to complete questionnaires designed to characterize their awareness of archeological values, their attitudes toward cultural resource preservation, and their perceptions of whether those programs met their expectations as educational experiences.

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[11] Hoffman, Teresa L. and Shereen Lerner. 1988. Arizona Archaeology Week: Promoting the Past to the Public. Paper presented at the 53rd Annual Meeting of the Society for American Archaeology, Phoenix.

Estimated cost: $2,000 per year for a period of five years = $10,000 total.

Example 4.--Smaller interpretive/educational efforts, such as brochures and self-guided interpretive trails at sites, should be evaluated by on-site interviews with a sample of visitors employing a brief list of standardized questions. Questions should address the visitors' perceptions about the quality of the interpretive products provided at the site and should assess whether the visitors' expectations were met. Examples of each type of prehistoric and historic site in the Forest cultural resources inventory should be studied. To accomplish this, cooperation will be necessary, and perhaps shared research programs developed with the National Park Service, State Park systems or other organizations.

Estimated cost of this research: $4,000 per year for a period of five years = $20,000 total.

CONCLUDING REMARKS

This proposed research complements and supports the National Recreation Strategy.[12] It will provide the quality information necessary to accomplish the proposed strategy in the most efficient and cost-effective manner and it will allow us to respond to the changing needs of Forest users, develop high quality public interpretation and education programs, and accomplish the job through partnerships.

APPENDIX A

CHAPTER 2390 of the Forest Service Manual deals with interpretive services planning and management. Interpretive services are designed to develop in the National Forest visitor an interest, enjoyment, and understanding of the natural environment. The objectives of interpretive services are:

1. To assist those visitors to the National Forest, research projects, and State and Private Forestry locations in gaining a greater appreciation of the role of conservation in the development of the Nation's heritage and culture.

2. To promote visitor understanding of the Forest Service, the National Forest System, Forestry Research, and State and Private Forestry programs.

3. To inform visitors of recreation opportunities and facilities on the National Forest.

4. To help visitors know and experience the natural environments.

5. To implement an interpretive program that helps solve management problems and aids in the development of public understanding of Forest Service management.

6. To expand the number of interpretive associations which contribute to public understanding of Forest Service practices, support interpretive services objectives, increase public awareness, and aid in management of National Forest resources.

7. To increase visitor understanding of natural and cultural history principles and their relation to land management techniques.

APPENDIX B

RELATED CONSIDERATIONS

During the course of our discussions and report preparation, the Public Education/Interpretation work group generated a series of recommendations which we present here for consideration. They are not projects necessitating formal and planned research; rather, they represent activities and products which we feel will greatly benefit the efforts to improve and manage public education and interpretation of cultural resources in the National Forests in particular and on public lands in general.

Evaluation of Future Interpretive Programs

An integral part of an interpretive program is a system to monitor and evaluate project activities. As demonstrated, although many successful outreach and public programs have been established, few contain a mechanism to measure, describe, and quantify the effectiveness or lack thereof of the programs, and to disseminate the information to participants and organizers of similar programs. Furthermore, few opportunities exist to share these results. In addition, some programs involve sites and issues important to another user: the Native Americans. When possible, Native American input should be sought and incorporated into project evaluation, as it provides a perspective necessary to the interpretive process. Likewise, feedback from visitors is crucial; their input may result in changes ranging from a simple modification in sign wording to adjustment in physical on-site behavior to prevent vandalism.

In effect, an evaluation aspect builds into the program a formal mechanism for determining whether or not the stated objectives were met; and if not, why not. Management decisions to continue, expand, eliminate, or repeat programs are all facilitated by the existence of evaluative data.

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[12] USDA Forest Service. 1988. The National Forests: America's Great Outdoors. National Recreation Strategy: Research Implementation Plan. Washington, D.C.

USDA Forest Service. 1988. Serving People by Opening the Doors to the Past: Cultural Resources Interpretive Action Plan. Southwestern Region, Albuquerque, NM.

Information Exchange

Numerous public-involvement programs have been implemented within Region 3 and across the nation. Yet, little is known regarding the content, duration, or success of these programs. It is recommended that some mechanism for information exchange be established. Proposed channels of communication are national and local forums, professional and amateur newsletters, and publications. For example, public outreach workshops or symposia should be part of the Society for American Archeology and Society for Historical Archeology annual meetings, and activity updates should be presented at local professional meetings. Several program-specific and professional newsletters are produced in which program activities could be reported. Finally, conceptual, methodological, and technological aspects of public involvement programs, especially successes or failures, should be published in the variety of journals available.

Popular Summaries

We see several advantages in producing popular summaries of technical reports generated by cultural resources projects. One advantage is the increased availability to the general public of current, understandable information about the past. Popular summaries written as byproducts of scientific projects will have the timely involvement of the project participants, thus increasing the accuracy of the publication. Public-oriented literature emanating from scientific projects supported by public funds provides a tangible return for the expenditure of tax dollars. The publication and marketing of these popular summaries through local or regional associations strengthens these partnerships and cooperative agreements.

We recognize the necessity of allocating additional resources toward the production of popular summaries. A commitment will be necessary from the contracting agency or office to provide additional time and funds in the project budget specifically for the production of a popular summary. Obviously not all cultural resources investigation projects can or should generate an additional summary for the public. Large-scale archeological or historical surveys and projects that deal with multiple periods of prehistory and history, for example, are reasonable choices for development of popular summaries. Similarly, the percentage of resources allocated to popular summary production will be correspondingly small in projects with large budgets.

Interagency Cooperation Through the Region 3 MOU

An arrangement to facilitate cooperation and technology transfer among agencies has recently been established with the signing of a Memorandum of Understanding among Region 3 of the Forest Service, the Arizona State Office of the Bureau of Land Management, Arizona State Parks, Arizona State Historic Preservation Office, Arizona State Land Office, and the Hopi Tribe. Although the semi-annual meetings called for in this MOU are primarily a vehicle to evaluate the Site Stewards Program, this MOU should be also be used as a forum for ensuring that information on public education and interpretive efforts is shared and that opportunities for interagency cooperation are explored.

Cooperating Educational Associations

Partnerships with local and regional interpretive associations (for example, the Northern Arizona Natural History Association and the Southwest Cultural and Natural Heritage Association) and non-profit educational societies should be encouraged to provide an additional avenue for cultural resources public education and interpretation. Forest personnel should be allowed reasonable amounts of time to work with these associations.

Publication and sale of interpretive literature through authorized cooperating associations should be supported by top management as an efficient means to publish and distribute interpretive literature free of the encumbrances and cost of doing so through GPO. Net profits can be donated by the associations to the Forest Service and used to support research, produce more special publications, and assist interpretive services.

The paramount value of of such partnerships lies in providing interpretive media that help Forest users enjoy the Forest in a safe and minimally abusive way, and understand the value of their Forest resources.

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Research Toward the Year A.D. 2000: Archaeology and the National Forests[1]

Steadman Upham[2]

Abstract. -- Key research themes are identified and discussed in relation to the cultural resources management obligations of Federal land managing agencies. Comprehensive programs of research are needed to resolve important issues in archaeology related to the development and collapse of social systems, site formation, and site transformation processes. Additional research is needed on the issues of adaptive diversity, archaeological visibility, site dating, and synthetic interpretive scenarios.

INTRODUCTION

My first professional contact with the U.S. Forest Service was in 1976, when I worked with A.E. Dittert, Jr. and other archaeologists from Arizona State University to complete an archaeological survey and mitigation of sites on several hundred acres of land northeast of Payson, Arizona. The land was slated for exchange to the private sector, but in 1976 the notion that private developers would use that land appeared remote. After all, the area was well out of town, and was only accessible by a rutted two-track that dissolved without ceremony in the slightest rain. Just less than a year ago, however, I had the opportunity to drive northeast along Highway 260 on my way out of Payson. There along the ridgelines where we had found, recorded, and tested a dozen pithouses and tri-wall structures, were the silhouettes of summer homes and condominiums. Apart from being startled by the pace of development in this Arizona community, these domiciliary testaments to contemporary land-use strategies brought home to me a disappointing professional message: the archaeological fieldwork we had done on these base-for-exchange lands, and the ensuing laboratory analyses permitted only the barest interpretation of prehistory.

Instead of data synthesis or a breakthrough in methodology, fieldwork and analysis provided but another assemblage of Verde and Tonto Brown (I still don't know which one has mica in the temper, or was it in the clay?), some non-descript lithics reflecting, as I recall, an "expedient" technology, and the standard ream of field notes, plan and profile maps, and laboratory work sheets. We had worked hard in the field for the requisite 10-week field season, and we had done the work under the close supervision of the temporary Forest Archaeologist. We had written and submitted a lengthy report, and it had been approved as a clearance document. But we didn't learn anything new about local and regional prehistory, or about archaeological methodology on this project. We didn't learn anything new, because we hadn't asked the right questions.

I find no basis for recriminations in this lost opportunity. Yet the kind of scenario I just described has been repeated again and again over the last two decades in the Southwest. I maintain that shoddy work is not to blame in such situations. Rather, I believe the opposite is true in most cases: fieldwork has adhered to the highest professional standards, and laboratory analyses have made use of state-of-the-art methods and techniques

[1]Paper presented at the Cultural Resources Research Symposium, National Park Service Albright Training Center, Grand Canyon, Arizona, May 1 - 6, 1988.

[2]Steadman Upham is Associate Dean of the Graduate School and Associate Professor of Anthropology at New Mexico State University, Las Cruces, New Mexico.

when possible. Why, then, don't we find theoretical and methodological breakthroughs by the yard in Southwestern archaeology; why don't we learn something new about prehistory and archaeology on each project we undertake?

I believe the answer to these questions resides in two separate but interrelated issues: First, the independence of archaeologists working both in and out of the federal bureaucracy has selected for a contemporary contract archaeology without regard for regional research designs. Such an absence is felt most critically in federal land-managing agencies who must administer diverse holdings, and whose typical CRM project is limited to small clearance surveys. Second, key prehistoric research themes, both methodological and theoretical, have not been widely accepted as generally relevant by the professional archaeological community.

In Region 3, these two issues have been addressed twice in week-long symposia over the past seven years, once under a framework similar to NARTS (National Archaeological Research Topics [Green and Plog 1983]), and once in the context of predictive modelling (Cordell and Green 1984). I was fortunate to be a participant in both symposia, and in this paper I incorporate many of the lessons learned during those thought-provoking sessions. In the remainder of this paper, I identify what I consider to be the central research issues for prehistoric archaeology on the National Forests of the Southwestern and Rocky Mountain regions. The way such issues articulate with integrated regional research designs is beyond the scope of the present paper, but has not been overlooked.

FOUNDATIONS OF AN APPROACH TO RESEARCH ON THE SOUTHWESTERN FORESTS

The American Southwest is one of the most ideal natural anthropological laboratories in the New World. In this geographic region, innumerable archaeological sites bridge prehistory and history and testify to long-term occupational continuity. Detailed, if incomplete historical and ethnographic records, augmented by deeply rooted oral traditions, back the continued existence of native peoples on their traditional lands. The Eastern and Western Pueblo, Ute, Pai, Pima, Papago, and Athapaskans are living testament to persistence on the land, and the details of their landscapes speak to the complex history and prehistory of these aboriginal peoples in the Southwest. For archaeologists, unparalleled conditions of preservation have been combined with sparse vegetative cover, a rich and highly variable archaeological record, trees that can be read like calendars, and an unbroken chain of human occupation that covers more than 10,000 years.

Moreover, details of the major events that punctuate the last 10,000 years of world history -- the emergence of agriculture, the beginnings of sedentism, the rise of village life, the formation of complex social systems, the proliferation of cultural and ethnic diversity, the formation of supra-village economic systems, the beginnings of pan-regional commerce, social and economic collapse, abandonment, European colonization, and the colonial legacy of enclavement and compartmentalization -- are written silently in the prehistory of the Southwestern region and between the lines of its incomplete historical and ethnographic records. Consequently, the limitations on defining *key prehistoric research* themes are only imposed by matters of individual preference, by long scientific and historical traditions that serve to demarcate important research domains, and by the connectivity of anthropological issues that invariably results from the interconnectedness of culture process. These elements unite to form a dominant research paradigm at any point in time, and the issues I identify below as "key" should be viewed in this perspective.

One of the most important functions of a research design is to identify research domains that distinguish relevant from irrelevant data. In this paper, I do not offer a research design, being charged instead with identifying key prehistoric research topics. In some respects, such an exercise is akin to reading a map without knowing precisely what the destination is. Nevertheless, I do believe that several key areas can be identified that structure most, if not all archaeological inquiry in the Southwest. I am instructed in my partitioning of Southwestern archaeological research by a few previous attempts to come to grips with this encompassing issue (Cordell, Schiffer, and Upham 1983; Cordell and Upham 1984; King and Plog 1984). I also draw on an important recent synthesis of Southwestern prehistory (Cordell 1984).

THE DEVELOPMENT AND COLLAPSE OF SOCIAL SYSTEMS

In previous Forest Service symposia, the topic of social development and collapse was discussed under a broader rubric, "The Rise and Fall of Civilizations" (Green and Plog 1983; Cordell and Green 1984). Although I participated in these symposia, I am no longer so theoretically expansive, preferring now to view the process of social development and collapse outside of pejorative labels like "civilization." Yet, like previous efforts I concur in part with the assessment for needed research on this general topic, believing that most, if not all of the substantive issues related to sequences of cultural development are subsumed by this theme. I believe the following major and minor research domains, while of intrinsic value unto themselves, must be addressed systematically if archaeologists are to be able to explain the development and collapse of Southwestern social systems.

Agriculture

The practice of agriculture in the prehistoric Southwest has continued to stimulate the curiosity of contemporary investigators, just as it did when the first corn cobs were unearthed in dry caves and rockshelters of the Four Corners area at the turn of the century. The aridity and generally marginal environmental conditions for agriculture in the Southwest have led many investigators to believe that a continued reliance on cultigens was an unlikely alternative for prehistoric groups. Over the years, many Southwestern archaeologists have assumed that risky environmental conditions made an agricultural lifestyle unpredictable and subject to periodic failure.

Now, Minnis (1985) has brought new information to bear on this topic and has indeed suggested that food stress and subsistence failure were common in some areas of the Southwest during prehistory. More critically, Minnis suggests that Southwestern groups knew about corn and other domesticates long before they began to rely on them; that the decision to practice agriculture was as much an organizational decision involving important social and economic criteria, than one related to perceptions of an improved subsistence base. Data clearly show that ignorance of cultigens or cropping practices did not keep past Southwesterners away from agriculture.

Like many important studies in archaeology, Minnis's work reminds us that questions related to the adoption and practice of agriculture can be framed in relation to time-space systematics (when and where questions), process (what and why questions), and cultural identity (who questions). In the late 1980s, it is appropriate that all three types of questions are relevant to archaeological research, depending on the nature and extent of investigation. At the present time, however, some categories of information on prehistoric agriculture and its relationship to the development and collapse of social systems are of more immediate importance than others. These categories are listed briefly below:

(a) Dating the Appearance and Adoption of Cultigens

Key questions remain regarding the earliest appearance of cultigens in the Southwest (Simmons 1985). Other questions relating to the differential adoption of agriculture also remain unanswered (Upham *et al.* 1987). A final set of questions pertains to the importance of cultigens in the subsistence regime of Southwestern groups, and the extent to which prehistoric Southwesterners relied on cultivated foods (Cordell 1984). Naturally, each of these questions has both a local and regional answer.

Partly as a result of Minnis' work, archaeologists have started to reexamine data related to agricultural beginnings in the Southwest and to identify when the first cultigens arrived in the region from Mexico. Indeed, one of the major topics of the 1980s in Southwestern archaeology has been the antiquity of the first maize (although squash was most certainly the first Southwestern domesticate). During this decade, positions have changed as more and more data have been made available. As the 1980s began and the re-excavation of Bat Cave was in progress, Southwestern archaeologists were moving toward revising the date for the earliest maize; 500 B.C. was a date frequently mentioned (Berry 1982). This very recent date contrasted markedly with Herbert Dick's published dates of 3500 B.C. (1965) for the Bat Cave material. A more recent date for the appearance of maize was also bolstered by radiocarbon dates between 1000 B.C. and 500 B.C. on Bat Cave corn (see Cordell 1984).

Yet some archaeologists have continued to maintain that maize has

considerably greater antiquity in the Southwest. This position has received a boost from two recent discoveries. Simmons (1986) dated organic material associated with maize pollen from sites in the San Juan Basin to approximately 2000 B.C., suggesting that corn agriculture, albeit at low levels, was being practiced in the Southwest by that time. In a second development, Upham *et al.* (1987) dated eight-rowed corn (Maiz de Ocho) recovered from rockshelter sites in the Organ Mountains of southern New Mexico to 1225 B.C. This latter find is especially significant in tracing the ancestry and antiquity of maize in the Southwest, because Maiz de Ocho is not the earliest variety of maize found in the region. That credit belongs to a maize variety known as Chapalote. Maiz de Ocho, however, appears to be indigenous to the Southwest, having developed in the arid deserts of southern New Mexico and northern Chihuahua as a hybrid from Chapalote and a more primitive eight-rowed variety (Upham *et al.* 1987). An estimated age for Chapalote given these new dates now appears to be about 2500 B.C. More research, however, is needed to date the appearance of maize in the Southwest in many different regions. Given the present information, differential rates of appearance, adoption, and reliance on cultigens would be expected.

(b) Identifying Southwestern Cultigens

It is assumed in traditional models of Southwestern agriculture that maize, beans, and squash formed the basis of agriculturalists' diet. More and more evidence, however, points to the use of a wide variety of cultigens, including the cultivation of native plants (Fish *et al.* 1985), and the manipulation (burning, pruning, etc.) of native species to enhance productivity. Before aboriginal agricultural subsistence systems can be described accurately, the full range of "crops" must be identified.

It is equally important to begin to evaluate the likely productivity and environmental tolerance of different strains of prehistoric cultigens. Archaeologists often hold such variables constant in reconstructions of past subsistence patterns. Yet, it is clear that significant productive differences between varieties of cultigens might have conferred differential competitive advantages to groups relying on them. Similarly, cultigens with high tolerance limits for variable climatic conditions might also have conferred significant advantages to particular groups. Experimental work, like that of Denmeade and Shaw (1960) or Classen and Shaw (1970), is needed to provide data on these important issues.

(c) Identifying and Explaining the Development of Agricultural Implements and Facilities

Twenty years ago, Ester Boserup (1968) pointed out that innovations in agricultural implements and facilities often result in increased agricultural output and demographic capacity. In the Southwest, the productive relationship between different kinds of agricultural implements (e.g. dibble stick versus hoe) is essentially unknown. Moreover, systematic data pertaining to the evolution of key agricultural facilities like storage units, water and soil control features, and field houses are lacking; developmental sequences for agricultural facilities are often anecdotal and localistic, and are rarely incorporated into regional culture histories. Broader level syntheses are needed to relate agricultural facilities to the agricultural system in use at any particular time. Recent work on Pajarito Plateau field house systems by Preucel (1987) exemplifies the kind of data needed to move forward in this area.

Demography

Issues related to the size, density, and distribution of population in the Southwest are at the core of virtually every significant problem in the developmental history of different regions, and are especially relevant to problems involving the development and collapse of social systems. Yet archaeologists have been unable to reconstruct, except with the crudest of measures, the demographic history of any single region with sufficient precision to offer *unequivocal* evidence that demographic factors were directly or indirectly related to other developmental processes. It is commonly assumed, for example, that the increasing size and density of a population is directly related to overall increases in the complexity of the sociopolitical organization, and to a variety of productive processes leading to craft specialization, subsistence intensification, and social stratification. I and many other archaeologists have advanced arguments based on this, or a variation of this theme. It is the case, however, that our measures of demographic variables

have often been rigid and have not reflected more than differences in the simple physical size of a settlement or series of settlements relative to those of preceding or subsequent periods. Key research needs to be undertaken on the way archaeologists estimate the demographic parameters of past populations, and specific attention needs to be paid to the biases of different estimators (e.g. floor area, number of rooms, site size, number of vessels per room, etc.).

Related to the actual measures used to reconstruct the size of past populations are processes that are believed to be causally linked to increases or decreases in demographic capacity. It is generally assumed, for example, that regional population growth is related to the shift from gathering and hunting to agriculture; that population growth led to territorial and/or resource circumscription, and "forced" populations to alter their subsistence strategies (cf. Cohen 1975). Support for this causal link is found ethnographically, and in episodes of economic development in the Third World (Boserup 1965), but archaeological data from the key epochs of world history provide conflicting evidence of the relationship between demographic and productive variables. The archaeological record of the Southwest provides a unique laboratory where key data can be obtained to study the transformation from food collecting to food production.

A series of issues have been raised recently that deal with the demographic characteristics, epidemiology, and sociopolitical organization of Southwestern populations, especially the Pueblos (see Upham 1986). These questions focus on *(a)* the size of native Southwestern populations, especially during the late prehistoric periods and early contact periods, *(b)* the role of epidemic disease and European-introduced acute crowd infections in population reduction immediately following contact, and *(c)* the degree and extent of complex sociopolitical organizations in the Southwest during the different prehistoric periods. Obviously, a full consideration of these issues is beyond the scope of the present paper. Suffice it to say, however, that the previous generation of archaeologists were heavily influenced by ethnographic descriptions of native Southwestern groups.

Today it is recognized that although the seminal ethnographies contain a wealth of valuable data, they depict the social, political, and economic arrangements *and demographic structure* of groups after a long and disruptive contact history. Population reduction due to disease and other factors, population dislocation and resettlement, the dissolution of native belief systems and their replacement by the Christian religion, and the imposition of new political and economic systems have all contributed to dramatic changes in native societies. Archaeologists have finally begun to examine the archaeological record in light of these changes and have sought to place the ethnographic descriptions of Southwestern groups in proper perspective. Continued research on these demographic and related issues is required to resolve the apparent conflict between the historic and prehistoric records.

Settlement

An obvious corollary to arguments involving demographic and subsistence change is found in the issues of residential mobility of past populations, and in the emergence of sedentism as a primary settlement strategy. The general patterns of world history suggest that a prerequisite for the development of emergent social and political hierarchies is a sedentary or semi-sedentary lifestyle, in which substantial portions of each year are spent in permanent settlements. Social and political systems characterized by emergent political hierarchies thus probably existed in very small numbers before the origins of agriculture and other strategies of food production. Based on archaeological and ethnographic data, their occurrence would be predicted in resource-rich environments, like those seen in temperate zones along the Pacific coast of North America at the close of the Pleistocene. Following the origins and spread of agriculture, the number of emergent social and political hierarchies increased rapidly.

Traditionally, sedentarization is linked to groups involved in food production, groups residing in those regions where sufficient natural resources permit the establishment of permanent settlements, or, more recently, groups in the throes of modernization or development. As such, sedentarization is normally associated with *(a)* certain kinds of environments (those either conducive to agriculture or naturally resource-rich), *(b)* surplus

production (at least production sufficient to carry a group through the four seasons of the year), or *(c)* the availability of resources or capital from more developed groups, a slightly different kind of "natural resource" (Kenyon 1959:35; MacNeish 1964:531; Braidwood and Braidwood 1953:278). I term this process *sedentarization through abundance*. Many discussions of sedentarization through abundance, especially in the archaeological literature, are thus directed to the study of purely environmental considerations (availability of water, amount and quality of arable land, abundance of natural resources, climate, etc.). If one were to survey the anthropological literature on sedentarization, especially in the Southwest, this pathway to sedentary life would appear virtually exclusive.

A focus on purely environmental issues and on sedentarization through abundance, however, obscures a very important issue. It is the case that another alternative, *sedentarization through impoverishment*, is just as common, if not more common, than the traditionally accepted explanation. Sedentarization through impoverishment has been occasionally described in the anthropological literature (see Barth 1961). Sedentarization through impoverishment can occur in a variety of ways but most often begins when population increases and a given landscape becomes "packed." Among pastoralists, a packed landscape decreases the amount of available pasturage, stimulates herd reduction strategies, and can result in the eventual loss of animals. If unchecked, entire herds can be lost and households can be forced to join existing settlements, almost always in dependency relationships with other households or supra-households and in circumstances of greatly reduced status. Among gatherer-hunters, a packed landscape decreases foraging range, increases competition for increasingly scarce resources, and may stimulate intensified procurement strategies. In the Southwest, like many other regions of the world, many such gathering and hunting populations may have responded to increased population densities by joining agricultural communities. Such communities existed as "magnets" on the landscape in much the same way that trading posts or mission stations do today in remote regions (Lee 1972a, 1972b). Exactly which communities were selected by gatherer-hunters may relate to long term social relationships between foragers and farmers and to the kinds of "alliances" described by Bender (1978:210-213). Gatherer-hunters, like pastoralists joining sedentary communities, also existed in positions of greatly reduced status.

Arguments seeking too strong a link between environmental variables and the process of sedentarization often mistake the environmental setting as causal. As I intended to show above, sedentarization through impoverishment is fundamentally a demographic process (Cohen 1977:83). As Hitchcock (1982:231) points out,

> Simple availability of resources (is) insufficient to bring about residential stability for an extended period of time..........Long term residential stability comes about when a group's mobility options are restricted due to the fact that there are too many other groups occupying the habitat.

Key prehistory research needs to be initiated to investigate the pathways to sedentarization in the Southwest. Given the variety of options available to prehistoric populations, there is no simple correlation between population size and density, mode of subsistence, and patterns of residential mobility. Rather, the weight of evidence strongly suggests that the causes and consequences of sedentarization are multiple.

Labor

In the Southwest, partly as a result of past interpretive traditions in American anthropology, it is not customary to suggest that human labor and labor processes were key variables in the developmental history of native groups. The lingering Apollonian perspective of the Pueblo coupled with other obfuscating interpretive elements (e.g., the land claims cases, see Upham [1987] for a discussion of this point), have combined to make discussions about the organization and management of labor *disputatio non grata* in the Southwest (for example, Reid [1985]). This view is unfortunate, since labor and labor processes are fundamental in all societies (Saitta and Keene 1988), even in the absence of social classes. In the Southwest, considerations of labor and labor processes are of importance to many different issues, but are of

critical importance to specific arguments about *(a)* agricultural intensification, *(b)* storage, *(c)* site construction, *(d)* productive specialization, *(e)* and exchange.

Several archaeologists have sought to show how variation in the organization and management of labor with respect to each of these issues affects the form, structure, and development of past social and political systems (Judge and Schelberg 1984; Lightfoot 1984; Upham 1982). Others have focused on broader processes, like the beginnings of agriculture or the pithouse-to-pueblo transition, that are evident in the archaeological record of the Southwest (e.g. Gillman 1987; Minnis 1985; Whalen 1984). More work needs to be undertaken on the organization of aboriginal labor and the way it was managed at the household, village, and regional level both for the specific research issues noted in the previous paragraph, and the more general pan-Southwestern processes identified above.

An example of how such research is accomplished, is illustrated by Betancourt, Dean, and Hull (1986), who add a new dimension to our understanding of resource extraction and labor management in the Chacoan regional system. Construction of the Chacoan road network, a feat requiring the mobilization of sizeable labor pools, has been directly tied to resource extraction activities necessary for construction and development of the canyon core (Betancourt, Dean, and Hull 1986). One such activity was the long-distance transportation of construction timbers, involving the movement of at least 200,000 logs more than 75 km. This kind of resource extraction posed a major logistical obstacle to the Chacoan Anasazi. Such an obstacle looms especially large in the organizational development of the system when it is considered that the average log measured of 22 cm in diameter, 5 m in length, and weighed 275 kg (ibid.,:370). Additional logistical activities associated with logging also necessitated the organization of substantial labor pools. Dean and Warren (1983:220-230), for example, detail how task groups "felled, trimmed, debarked, sorted into size classes, and cut to predetermined beam lengths" the hundreds of thousands of timbers required for construction.

When one begins to attach people to this enterprise, the meaning of this undertaking assumes far greater importance. Although the exact number of people required to complete this project remains unclear, it is certain that the number was in the hundreds, if not thousands. These people would have had to have been provisioned during their trips to procure timbers and such systematic labor would have had to have been supervised, even if only at a rudimentary level. Similarly, it is unclear if major logging expeditions were mounted from the canyon proper, or if logistical groups from outlying communities nearer to the timber sources actually supplied the requisite labor. In some respects, the exact form of logistical organization is irrelevant since both logistical strategies suggest very centralized control over the organization and management of labor. The latter strategy, however, suggests a higher degree of systemic integration throughout the Chacoan regional system.

What is clear from the recent work of the Chacoan researchers is that the 402.3 km of major and secondary Chacoan roads that have been identified, and especially the 9 m wide Great North Road, West Road, and Southeast Road, were built to surmount the obstacles posed by such monumental undertakings. Moreover, the labor requirements of this specific task, that may have required the involvement of many different population centers, provides important new information about the overall integration of the Chacoan system. Inferences about increased integration are bolstered by additional documentation of an elaborate system of signaling stations that linked Chacoan outliers together and to the major population centers in the canyon core (see Cordell 1984:256). In the case of the Chacoan regional system, Betancourt, Dean, and Hull's research augments previous analyses, and is indirectly tied to the nature of formal links in the system (especially, roads and signaling stations) that integrated populations who occupied the San Juan Basin during the eleventh through thirteenth centuries. More research in this *genre* is needed on many issues, but especially on those related to site construction, agricultural strategies, and craft production.

Economy

It is axiomatic to suggest that all of the above topics are interrelated, but nowhere are such interrelationships as evident as in discussions of variation in the economies of prehistoric groups. My treatment of economic issues must necessarily be

circumscribed by the limitations of space, as well as by the present ability of archaeologists to describe and explain elements of prehistoric economic systems. Consequently, rather than discuss "economies" *per se*, I will focus my remarks on one of the outward manifestation of viable economic systems: local, regional, and pan-regional exchange.

The role of exchange in the development and collapse of past social systems has been one of the dominant topics in anthropology during the last decade. Although opinions vary over how important exchange might have been as a motivating factor in the evolution of hierarchical social and political systems (compare, for example, Blanton *et al.* [1981] with Sanders [1972]), few dispute the fact that exchange is involved in this change process.

In a previous paper (Upham 1986:212-213), I have discussed variability in exchange systems, paying particular attention to exchange systems that operate at different scales and involve different spheres of exchange. I identify a local exchange system as one that operates within the confines of a single, spatially restricted settlement system. Elsewhere, I have termed such settlement systems *settlement clusters* (Upham 1982). Present data suggest that the overwhelming majority of commodities during all periods of Southwestern prehistory were locally exchanged. Regional and pan-regional exchange systems, on the other hand, are those that involve the exchange of goods between discrete settlement clusters in one region, and between groups of settlement clusters in different regions, respectively. Regional exchange appears to have involved more labor intensive or scarce goods like polychrome pottery and varieties of exotic materials, such as turquoise and certain minerals and pigments. With the exception of marine shell, which could have been traded in a down-the-line fashion, pan-regional exchange is barely visible archaeologically during most periods of Southwestern prehistory.

At the present time, archaeologists have a poor idea about the range of commodities that might have been regularly exchanged at the local and regional levels. Foodstuffs, for example, are assumed to have made up a substantial portion of the exchange base among many Southwestern groups (cf. Cordell 1984). Moreover, the exchange of food figures prominently in many Southwestern interpretive scenarios (e.g. Plog 1974; Lightfoot 1979) that posit redistribution or other economic levelling or buffering mechanisms. Yet in only a few cases can the exchange of food be unequivocally documented. Research needs to be undertaken that focuses on this important issue. Perhaps the most promising line of research pertaining to this issue involves isotopic analyses of various cultigens that "fingerprints" trace elements unique to particular geographic locations. Recovered plant macrofossils as well as food residues found on pots, potsherds, and food processing implements are amenable to such analytical techniques.

The ability to fingerprint trace elements and identify various geographic locations is also the analytical underpinning of other sourcing techniques that are now used routinely on Southwestern ceramic and lithic materials. The increasing use of source analyses in Southwestern exchange studies marks an important change in Southwestern archaeology. In many cases, the suspicion of widespread exchange of a particular commodity can now be unequivocally verified. Such verification has raised a variety of new questions about the structure of prehistoric exchange systems that could not be asked even five years ago. The recent work of Bishop *et al.* (1988) on the Jeddito Yellow Wares, for example, clearly identifies site-specific chemical signatures, and exemplifies the kind precision that can be expected in future source analyses. More importantly, however, the acquisition of site-specific chemical signatures also permits detailed reconstructions of the exchange network that emanated from any particular manufacturing center. Such work is limited only by the archaeologist's ability to acquire, analyze, and (pay for!) interpret relevant sherd samples. Work that follows the model of Bishop *et al.* should be undertaken on other ceramic wares and on the plethora of distinctive lithic materials found on Southwestern sites.

A separate but related area of inquiry that follows from the source analysis of artifacts is stylistic analysis that is focused on identifying the spatial distribution of distinct stylistic elements and motifs (Wobst 1974, S. Plog 1980; Wiessner 1983; Sackett 1985). Such research should be viewed as the natural extension of physico-chemical source analyses in exchange studies, and should be used to

identify prehistoric *information networks*. Such information networks may not always be isomorphic with networks in which material circulated. Rather, cross-cutting and/or overlapping ties are expected to have occurred along with those that parallel the direct transmission of commodities between groups.

Environment

It is not possible to write a paper about key research in the American Southwest and omit from consideration the general topic of environmental variability. I am, however, sorely tempted to do just that, to omit from consideration a discussion of research related to environmental variability and paleoenvironmental reconstructions. My reasons for such temptation are twofold. First, the contributions of one recent research project involving Gumerman, Dean, Euler, Hevly, and Karlstrom have been substantial, not only breaking important new ground, but also providing substantive results and direction for future research (Dean *et al.* 1985; Euler *et al.* 1979; Gumerman *et al.* in press). This comprehensive research should serve as a model so that future work in other areas of the Southwest can provide complimentary data on dendroclimatology, hydrology, palynology, and geomorphology in conjunction with archaeological data. Expanding from Gumerman *et al.*'s Black Mesa data set will enable archaeologists to correlate results across regions, providing many new insights into the affects of the paleoenvironment on culture processes.

Second, although there is no question that the exigencies of the natural environment affected the course of development of all prehistoric Southwestern groups in one fashion or another, it is becoming increasingly clear that cultural variables (demography, economy, etc.) were important, and in some cases more important, in structuring the character of a group's adaptation to particular environments. An abundant literature has now developed in Southwestern archaeology devoted to describing and explaining the way past environments altered, channelled, and facilitated the course of prehistoric cultural development in relation to social factors (see Cordell [1984] for a summary of this work). This work too has broken new ground and points the way for future research related to the development and collapse of social systems.

Given the substance of the work noted above, I defer at this juncture to offer anything more than my positive endorsement of these two categories of research. Active support for research programs to continue these efforts is encouraged, and the ensuing research should have a substantial payoff in years to come.

An active program of archaeological research undertaken with the six topical areas discussed above in mind will result in major advances in our general understanding of how social systems evolve, and will add to our more specific knowledge of local and regional developmental sequences in Southwestern prehistory. Such research, however, can only move forward in tandem with thoughtful methodological inquiry into the nature of the archaeological record, with specific examination of site formation processes, post-depositional transformation processes, and biases in data produced by observers and different field and analytical strategies.

SITE FORMATION, TRANSFORMATION PROCESSES, AND OBSERVER BIAS

Six years ago, Dee F. Green, then Regional Archaeologist for the U.S.D.A. Forest Service, Southwestern Region, and I wrote a research proposal to the National Science Foundation to study site formation processes, post-depositional transformation processes, and variation in survey data produced by observer biases (Upham and Green 1982). We planned to use the National Forests in the Southwestern Region as natural laboratory for a program of experimental archaeology that would assess the affects of various management and recreational processes on archaeological sites. After receiving an "excellent" rating on the proposal by anonymous reviewers, the NSF panel judged this research as both "too applied" and "risky", since it would bring the funding of research dollars normally intended for academic archaeology squarely to the portal of a CRM-oriented project. Additional concern was voiced over the fact that Green and I had planned to use a variety of real and manufactured archaeological sites for experimental purposes. Because I still believe that the research we outlined in 1982 is relevant today, I quote large sections of our proposal below in the hopes that it will stimulate other archaeologists involved in archaeology on the National Forests to take up the cudgel that Green and I reluctantly set aside.

Motivation for developing our NSF proposal derived from Green's and my concern over the increased pace of contract archaeology, in which more and more people with minimal academic training were being used as quasi-professional crew members on large-scale survey projects. Prior to 1974, archaeological work in the American Southwest had traditionally focused on excavation. During the last 15 years, however, the number of archaeological site surveys undertaken has dramatically increased. There are several reasons for this increase, not the least of which is the demand created by private developers, state and local governments, and Federal agencies for archaeological clearance work in compliance with cultural resource laws and regulations. The increase in site survey work has created much discussion within the discipline regarding the techniques and methods appropriate for management projects. One important aspect of these discussions has been the recognition that many current archaeological field methods are based on unexamined assumptions about the nature and character of the archaeological record.

There is a growing recognition that the archaeological record is not a static phenomenon, but one that is subject to a variety of external processes that affect the way archaeological materials (artifacts and features) are spatially distributed. Perhaps the most complete theoretical treatment of the potential transformation processes that can affect the archaeological record has been presented by Schiffer (1976, 1977, 1983, 1985). Schiffer describes a variety of different natural and cultural transformation processes that can alter the integrity of archaeological deposits. He also illustrates the dynamic character of the archaeological record by describing how archaeological materials can move between archaeological and systemic contexts. Most substantive attempts to define the extent and magnitude of various transformations have focused on natural processes affecting the archaeological record. Wood and Johnson (1978), for example, have identified a variety of natural forces (faunalturbation, floralturbation, cryoturbation, graviturbation, argilliturbation, aeroturbation, aquaturbation, crystalturbation, seismiturbation) that have the potential to displace, mix, and alter the integrity of archaeological deposits. This and other studies (Benedict and Olson 1978; Krause and Thorne 1971; Limbrey 1975; Rick 1976) follow from Ascher's original observation that a site's deposits exist in a dynamic matrix and are subject to variable degrees of contextual and associational change (1968).

Another genera of studies that have dealt with the formation and transformation of the archaeological record focus on the structural relationships between archaeological data, archaeological context, and the natural environment (Sullivan 1976, 1978; Jorgensen 1975; Wilcox 1975, 1977). Although these studies are, in large part, derived from the original work of Schiffer, they differ in one important respect: they attempt to define the logical relations between context (surfaces, deposits, features), objects (artifacts and materials used in past behavioral systems), and environment (including contexts transformed by natural processes). While such work shows promise, quantifying the effects of the environment has proven problematic.

Most archaeological research dealing with transformation processes has been directed toward understanding and measuring the natural forces responsible for altering archaeological deposits. Schiffer, however, correctly points out that both natural and *cultural* forces affect the surface and subsurface character of sites. While most archaeologists accept the fact that such transformations do occur, few archaeologists have attempted to measure the rate of change or the magnitude of change induced by cultural transformation processes (Burgh 1960; Bryant, Gehr and Flenniken 1981; DeBloois, Green and Wylie 1974; Lightfoot and Francis 1978; Wood 1979).

Another kind of cultural transformation process that is often neglected has to do with the introduction of observer bias during the collection of archaeological data. The increase in the number of site surveys has been accompanied by a growing awareness that archaeologists can introduce biases by the way they locate, identify, and record surface manifestations. Plog, Plog, and Wait (1978) have illustrated how variation in site densities and artifact inventories in particular regions can be largely the result of differences in observations and in the ways surveys were undertaken by different crews of archaeologists. A similar result was obtained by Bergman (1980) who found that different survey techniques and intensities resulted in substantially different findings,

depending on the amount of vegetative cover and the degree of alluviation. Both studies are beginning points; yet much remains to be learned about how different survey conditions (vegetative cover, weather, terrain) and differences in training and expectations of the survey crew affect the quality and reliability of survey results.

Key research needs to be undertaken on measuring the effects of several cultural transformation processes that occur routinely both in the course of management of Federal lands and in the performance of archaeological surveys for cultural resources management purposes. Such research could be ideally structured around the multiple-use activities of a National Forest. Consequently, a coordinated program of experimental archaeology, using both real and manufactured sites needs to be established to monitor the effects of various activities that occur as the Federal land-managing mandate is carried out.

Transformation processes and observer biases have important implications for interpretations that archaeologists generate from survey records. If site surfaces have been dramatically changed both by natural and cultural impacts, then site survey information on artifact context, association, and relational patterning are of little utility. Similarly, if different archaeologists do not consistently recognize, identify, and record the same types of information with the same potential error factors, then any apparent cultural variation between areas may simply be a product of the way the surveys were conducted.

Archaeologists have generally assumed that meaningful interpretations of past human behavior can be derived from inventories of surface remains. However, if we are to provide such interpretations from surface remains, the effects of transformation processes and measurement error by survey crews need to be measured. Assessing the effects of transformation processes and observer biases is particularly critical now, when millions of dollars of public money are being spent to inventory large portions of the Southwest.

It is clear that any attempt to assess the potential effects of natural and cultural impacts to site surfaces requires carefully controlled experiments that are designed to produce both short-term and long-term results. In addition, a natural laboratory is needed where impacts to archaeological sites result from relatively routine economic and recreational activities. Key research on this topic should allow for such experiments in a forest setting, and should be designed to quantify the way particular activities affect the character of archaeological sites. Given that archaeological survey is also a routine activity on the National Forests, experimental designs should be developed to measure variation in survey and recording techniques, and to identify cost-effective solutions to managing the disparate data bases that are created by this kind of observer bias.

Archaeologists and land managers alike need quantified and verifiable information on the effects of various human and natural phenomena on cultural resources. In many instances, archaeologists are in positions to influence decisions about the kind of activities that take place in particular areas, especially on federal and state land. These management decisions are often made without sufficient data to assess fully the impact of particular activities on archaeological sites. There are few experiments, for example, which quantify the actual horizontal and vertical displacement or loss of artifacts as the result of traffic (vehicular, human and animal) over a site (Bryant, Gehr and Flenniken 1981; DeBloois, Green and Wylie 1974; Wood 1979). The results of these studies are largely unsatisfactory owing to the absence of experimental controls. For example, the kinds and rates of artifact loss or displacement from sites near recreation areas are unknown; the actual effects of timber harvest operations, of controlled or uncontrolled fires, of grazing and other multiple resource uses are also unknown. Finally, the effect during site survey of differences in crew training, crew spacing and crew expectations has not been measured. Each of these has the potential to affect the reliability and, consequently, the interpretations derived from surface data.

Despite the lack of knowledge referred to above, archaeologists and land managers must continue to make judgments about the nature, value, and disposition of cultural resources. There is an urgent need to rectify the situation and provide the necessary data that will form a basis for making sound and cost-effective decisions about cultural resources.

INTERPRETIVE ISSUES AND TECHNICAL RESEARCH

One of the dangers in writing a paper that attempts to provide a comprehensive summary of research needs in a particular field is knowing when to stop. It is clear the dozens of other general topical issues could be raised in an essay of this sort that would be equally important as those already discussed. Because such coverage is clearly beyond the scope of the present enterprise, I chose to focus my remaining remarks on interpretive issues in Southwestern archaeology, and on problems related to technical research that must be completed if satisfactory resolution of these key interpretive issues is to occur.

In the following section, I identify two specific issues where technical research is needed to resolve disparities in interpretive positions. Both of these issues are tied to various parts of the previous discussions, and have implications for the way archaeologists view critical aspects of Southwestern prehistory. I conclude this essay with a summary of an interpretive position that has been advanced by several archaeologists that challenges key portions of existing culture history. Resolution of the issues raised here will require a comprehensive program of integrated research. Such research could be effectively coordinated under the auspices of the U.S.D.A. Forest Service, utilizing the diverse cultural resources found on the National Forests of the Southwestern and Rocky Mountain Regions.

The Definition of Culture and Adaptive Diversity

An earlier generation of archaeologists devoted its time to defining archaeological cultures and to refining local and regional phase sequences within a given culture area. Largely because of this pioneering work, archaeologists are now able to address other questions about culture change and stability. The identification and definition of archaeological cultures, however, are no longer viewed as scientifically justifiable pursuits in the field of Southwestern archaeology. Instead, contemporary archaeologists have sought to describe and explain aspects of the social, political, and economic systems for different Southwestern groups, and to characterize broad patterns in the adaptive history of regions. In the Mogollon and Anasazi areas, for example, several studies during the last five years have offered synthetic treatments of these issues at the regional level (Kintigh 1985; Lightfoot 1984; S. Plog 1986; Upham 1982). More importantly, however, Southwestern archaeologists have not proceeded to broader level syntheses in the absence of theoretical underpinnings. Models from economic geography, theoretical ecology, and evolutionary biology have all been adapted with varying levels of success. Some commentators have viewed these developments with alarm, citing the lack of unity in approaches and methods. Others, while acknowledging the "creative chaos" in approaches, view such work as largely positive (cf. Cordell 1984).

Although the eclectic nature of the field is well expressed in the diversity of approaches alluded to above, such eclecticism has not produced totally diverse and unrelated interpretations. A growing consensus is emerging, based on research conducted in many different regions, that Southwestern societies developed organizational strategies that were extremely *resilient* over long periods of time. These organizational strategies were not fixed and immutable once set into place, as some phase sequences would suggest. Instead, they were flexible and permitted wide latitude in a group's organizational responses to the exigencies of the natural and social environments. Braun and S. Plog (1982), Cordell (1984), Cordell and F. Plog (1979), F. Plog (1984), and Upham (1984; 1988) have all presented formulations that reflect this position. These researchers depict the archaeological record as a chronicle of organizational diversity that not only shows simple and complex organizational structures, but also portrays variability in these structures through time. Such a recognition has clear implications for non-linear developmental sequences and variability in rates of culture change.

Archaeological Visibility

The time-worn saying "Out of sight, out of mind" seeks to encapsulate the idea that perception is guided by what is prominent and conspicuous. Visibility leads to recognition; obtrusiveness garners attention. In archaeology, these dictums have meaning at the most basic scale of archaeological observation: describing and explaining variation in the archaeological record. It is true, for example, that the size and mobility of

any given population is proportional to the obtrusiveness of the remains it leaves behind. Archaeological remains produced by small, highly mobile gathering and hunting groups differ substantially from those of sedentary village or city dwellers. These latter adaptations often result in profound alterations to the landscape that are obtrusive and easily recognizable, even after hundreds or thousands of years. Gathering and hunting adaptations, on the other hand, result in much more ephemeral records of occupation that are easily blurred or obscured by later human activity, or simply by the passage of time.

If one accepts this reasoning, then the obtrusiveness of archaeological remains increased dramatically with the development sedentism and the emergence of food production. The emergence of food production and subsequent developments in technology, sociopolitical organization, economy, and ideology have been the focus of most archaeological work since the turn of the century. These developments have preoccupied archaeologists largely, I suggest, because the visibility and obtrusiveness of remains produced after A.D. 500 in the Southwest overwhelm those from earlier periods. It is also the case, however, that the adaptive history of the last 1500 years of some regions has been written as if the more obtrusive patterns were characteristic. Low visibility archaeological remains generally have not been a focus of study in regions where the remains of obtrusive patterns also exist.

It should be understood that equating low visibility remains with with gathering and hunting groups is over simplified and in some ways metaphorical. But my purpose is to illuminate structural differences between gathering and hunting and other adaptations that are based on food production. Archaeologically, there are vast differences in the kinds of remains produced by adaptations based on gathering and hunting and food production. Consequently, the metaphor can be used to illustrate how our interpretations of past human occupations in some regions have been influenced by the visibility of remains and by an over-attention to large sites or elaborate architecture. Contemporary Mayanists are still seeking to balance a prehistory that became overwhelmingly biased toward ceremonial centers during the first fifty years of this century (Marcus 1983). In the American Southwest, the "San Juan centric" view was dispelled during the 1940s (Reed 1942, 1948), but the prehistory of Chaco Canyon and Mesa Verde is still perceived by many to be "Southwestern archaeology." In this case, our perspectives have been shaped literally by what is most visible on the landscape. Our "field of vision" has been focused on, and in many cases restricted to architectural remains: villages, towns and cities.

The situation described above holds true especially in what are perceived to be extremely well known culture areas. In the American Southwest, for example, we know a great deal about Puebloan prehistory, especially *after* pithouse villages began to be built and the adaptive pattern was characterized by a measure of sedentism. The outlines of Southwestern prehistory are more poorly known for earlier periods. Conversely, during later periods in the Southwest, including the early historic period, groups who were mobile and did not live in permanent villages have virtually escaped archaeological interpretation. Only a few Manso, Yavapai, Apache or Seri sites have been recorded by Southwestern archaeologists, despite widespread and historically documented occupations. We have emphasized the more obtrusive patterns and constructed our periodization schemes based on the waxing and waning of their remains, in some cases to the virtual exclusion of any other patterns. Consequently, in many areas of the Southwest, especially those characterized by abandonment or collapse just before recorded history, the description of low visibility adaptations has been left to Spanish chroniclers or early travelers who have provided, in some cases, the only written record of the group's existence. This situation pertains even to those areas where low visibility adaptations were the characteristic pattern for *most* of the prehistoric period (cf. Upham 1984:243-245).

The issue of abandonments or collapse raises another important point related to low and high visibility remains. Because our periodization schemes are most often founded on the remains of the obtrusive archaeological patterns, shifts in adaptive strategies often go undetected by archaeologists. Adams alludes to this problem by expressing concern for identifying "transitional processes" that bridge "disjunctions" between periods of stasis (1984:82). It is the case that the record of human occupation in most areas of the Southwest is remarkably continuous, but the record of social, political, and economic development in

these same areas is often discontinuous. Continuity in social, political or economic development for more than a few hundred years is rare. Archaeologists use terms like abandonment and collapse to describe these latter "discontinuities", but in many cases what they are really referring to is the disappearance of the specific developmental pattern, not the disappearance of the people. Thus, one could argue that terms like abandonment, hiatus, or collapse are really archaeological shorthand for the episodic character of cultural development in the Southwest. Unfortunately, by using these terms our perceptions are focused on concepts that emphasize an absence of occupation rather than on ideas that seek to identify low visibility occupations and explain how transitions from high to low visibility adaptations occurred.

Redressing this problem often requires more than simply shifting one's interpretive emphasis. In the American Southwest, the time-space frameworks that exist in many cases actually preclude consideration of low visibility adaptations in the archaeological record. Constructing interpretations to account for this kind of adaptive variability often means confronting virtually every traditional assumption that has guided the work of Southwestern archaeologists since the turn of the century. Specifically, I maintain that the failure to distinguish between high and low visibility adaptations in the archaeological record has produced an *underclass* of Southwestern prehistory (cf. Upham 1988). By underclass, I refer to those groups in the Southwest whose adaptations, because of their unobtrusive character, have not been the subject of anthropological inquiry.

Key prehistoric research is needed on this important issue. Particular emphasis needs to be given to identifying and describing low visibility archaeological remains, and to explaining how such sites articulate with the broader patterns of settlement so often described in the culture histories of the Southwest. National Forests of the Southwestern and Rocky Mountain Regions provide an exceptional natural laboratory where appropriate field strategies can be developed and where experimentation can be initiated on analytical techniques that will facilitate modelling of low visibility phenomena.

Chronometric Dating

Very little work in archaeology can proceed in the absence of chronometric dating. The ability to date site occupations undergirds virtually every important aspect of archaeological interpretation. As Cordell, Schiffer, and I noted in the first Forest Service symposium on cultural resources,

> One of the most persistent obstacles to processual studies continues to be our inability to date precisely past cultural events, such as the manufacturing span of pottery types, the founding and abandonment of settlements, and the emergence at various scales of regional systems. Moreover, without sound chronological frameworks, it is nearly impossible to conduct refined studies on rates of change in behavior or organization, or to correlate changes in cultural phenomena with changes in environmental conditions (1983:25-26).

We went on to identify a dozen different research needs in the area of chronology. Although progress has been made on some of the 12 issues we raised, much work still remains. Rather than recapitulate these points, however, I refer the reader to our original article, and offer a more general discussion of needed chronological research, citing two examples where interpretation is presently impeded because of a lack of chronological precision.

In the Southwest, the development of dendrochronology has contributed to perceptions outside the region that unparalleled chronological precision is possible; that site dating is easy and certain. Such a perception has been enhanced by a number of other recent dating advances: *(a)* progress in dating small samples of organic materials by the radiocarbon method using technology derived from the linear accelerator and mass spectroscopy, *(b)* the development of new secular variation curves for archaeomagnetic dating, and *(c)* experimentation with methods of laboratory-induced obsidian hydration dating. These advances coupled with existing methods of relative dating (especially ceramic and lithic typologies) might suggest that the Southwest continues its role as

archaeology's chronological "Garden of Eden."

It is true that the Southwest has been a center for research on dating techniques (both relative and chronometric). The region also appears to provide more opportunities to use these techniques because of favorable conditions of preservation and the presence of suitable materials, like obsidian, for dating. Moreover, the past history of research on ceramic and lithic typologies in the Southwest has portrayed to outsiders an image of dating precision in the use of relative dating techniques. A number of analyses of material culture calibrated by dendrochronology or other advanced chronometric techniques, however, have presented data at variance with existing interpretations and typologies. Consequently, a re-examination of culture historical frameworks has begun.

Two areas of research are especially important. First, it has become clear that some projectile point styles are poor temporal indicators. This finding is important because Southwestern archaeologists routinely use projectile points to date sites and assign cultural affiliation. Obsidian hydration dating of San Pedro style points, commonly dated to the late Archaic period (1500 B.C. to A.D. 200 [cf. Haury 1950]), documents the persistence of this point style in some Southwestern regions well into the fourteenth century (Upham *et al.* 1986). Such persistence appears to be linked as well to the persistence of gathering and hunting adaptations and, consequently, re-examination has begun in many regions where such projectile point styles have been used to date "Archaic" age sites. Other analyses of so-called "archaic" style points also suggest that their temporal spans need to be reevaluated (Cordell 1984). Thus, chronometric dating has opened a new interpretive avenue by revealing the persistence of gathering and hunting during the late prehistoric period, and has called into question the temporal sensitivity of the traditional projectile point typology.

Second, it has been recognized that some Southwestern pottery types are not as temporally sensitive as once thought. Specific types of black-on-white pottery, for example, have been found to occur with much later polychrome, glaze, and/or black-on-red (orange) types. These inhomogeneous distributions have been documented for much of the plateau and montane regions of the Southwest (Upham, Lightfoot and Feinman 1981; Lightfoot and Feinman 1982; Lightfoot 1984; S. Plog 1986; Upham 1982). The co-occurrence of apparently "early" with late ceramic types has substantial implications for interpretations predicated on the contemporaneity of different kinds of sites in settlement systems. For example, in a recent synthesis of pithouse occupations in the Apache-Sitgreaves Forest (Hunter-Anderson 1986), an important conclusion is offered that suggests an increasing use of horticultural products through time, a process that is correlated with a reorganization of domestic activities in houses and an increase in storage space. Hunter-Anderson argues such changes are related to developing sedentism and to the need to store food for overwintering. This conclusion is dependent on an analysis that begins by partitioning sites into different time periods using a relative dating technique (dating by ceramic types). The ceramic typologies used by Hunter-Anderson are Colton's and related classification schemes that are not sensitive to the early-late co-occurrence phenomenon. These same changes in subsistence, residential architecture, and artifacts noted by Hunter-Anderson have been identified by other Southwestern archaeologists and have been interpreted in quite a different fashion. For example, citing inhomogeneous distributions of ceramics (as well as other data), Lightfoot and Feinman (1982) argue for greater contemporaneity among sites than does Hunter-Anderson, and for differences in status among and between site residents. I too have argued that intra-site and inter-site status differences occurred among some prehistoric populations during certain periods of prehistory, and have suggested that such patterns obfuscate what appear to be relatively straightforward chronological differences (Upham 1982, 1988).

Additional chronological research is needed to resolve these interpretive discrepancies. Such research needs to be systematic and extensive. A compendium of chronometric dates is needed to calibrate the date spans of particular diagnostic artifacts (decorated ceramics, projectile points, etc.) for each major region in the Southwest. A beginning point for such research is to incorporate into all scope of work statements the mandatory acquisition of chronometric dates for each project undertaken on the National Forests.

CONCLUSION

In the introduction to this paper I offered my lament over our inability to interpret the prehistory of the Payson area in relation to the broader themes of Southwestern prehistory. My lamentation is tied to the belief that overarching research themes, and comprehensive regional research designs *must* guide all archaeological inquiry. Such an approach requires interpretive scenarios that can be tested and evaluated with data acquired from each new project. Such an approach is also dynamic, leading to constant "tuning" and refinement of research themes, research designs, and (most importantly) interpretive scenarios. In this kind of enterprise, there is no room for professionally guarded "truths", or scientists who cling too tenaciously to pet theories. Instead, there are only slates of ideas that can be offered up, evaluated, accepted, rejected, or refined. I believe the above description of an "action plan" adequately describes the process of research. Within this infrastructure of research, those who undertake programs of attack, especially those who vilify other investigators, are not fit for the research enterprise and should be restricted in their participation.

Over the past decade, several interpretive scenarios have been developed that fit the research model I describe above. One of the most encompassing pertains to the late periods of prehistory and to the early contact period, when large Puebloan populations covered much of the central and northern Southwest. Aspects of that scenario are speculative, and require substantial additional research. Other elements of the scenario appear valid based on existing data, and lend tentative support to a revisionist notion of prehistory.

This interpretive scenario contains four primary points:

1. Catastrophic population loss during the first seventy-five years of Spanish contact, a process largely undocumented in the historical records of the northern Southwest, resulted from the introduction of acute European crowd infections (smallpox, measles, and influenza [Reff 1986 ; Upham 1980, 1982, 1986]). Moreover, initial epidemics appear to have spread within native interaction networks, and may have preceded actual face-to-face contact with the Spanish.

2. The loss of native population and the ensuing Spanish program of settlement reduction, missionization, re-education, and agricultural retraining inexorably changed the sociopolitical and economic fabric of native society (Upham 1980, 1982, 1983; Wilcox 1981). This colonial onslaught, although experienced differentially by various native groups, resulted in community enclavement and compartmentalization, a breakdown of inter-community ties, and perceptions by later historians and anthropologists that the distinctions between Southwestern native groups were more significant than similarities of economy, politics, and religion.

3. Late prehistoric and contact period populations in the central and northern Southwest were not uniformly sedentary, nor did they all reside in communities built in the characteristic pueblo style. They were, instead, an amalgam of both sedentary pueblo-dwellers *and* indigenous gatherer-hunters, a fact clearly reflected in contact period narratives written prior to A.D. 1600 (Upham 1982, 1984). This population structure has substantial implications for reconstructions that focus on regional interactive ties, and the amity-enmity relationships that characterized different sub-regions of the central and northern Southwest prior to and during the years of initial Spanish contact; and

4. Interdependent regional settlement systems were present during the late prehistoric period in the American Southwest and, although substantial organizational variability existed, hierarchical sociopolitical structures and managerial elite were extant in more than a few of these systems (Upham 1982; Lightfoot 1984; Upham and Lightfoot in press). Such organizational configurations facilitated high levels of inter-regional exchange (of various commodities), and exchange ties between communities and regions appear to have linked diverse populations in ways that transcended simple trading-partner relationships.

The point of offering this interpretive scenario is not to claim that it is right, but to provide a context for evaluating archaeological data from the late prehistoric and contact periods. Had such a scenario been extant in 1976, explicit hypotheses could have been derived from the

scenario, and some of the data from the Payson region might have been more parsimoniously described and explained. More importantly, however, the data from the Payson region might have aided in refining the interpretive scenario.

What is needed at this juncture in the development of Southwestern archaeology are more comprehensive scenarios for other regions and time periods. Wilcox and Sternberg (1983) have provided a comprehensive interpretive scenario for the Salt-Gila area of the Hohokam region; Judge and Schelberg (1984) have provided a beginning point for the development of such a scenario for the San Juan Basin. Doubtless other beginning points can be found. Active participation by the cultural resources management programs of the U.S.D.A. Forest Service in such a program of research will facilitate the development of this kind of approach, and over time will contribute to meaningful advances in our understanding of the human past in the Southwestern and Rocky Mountain Regions.

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Delivering the Past: Prehistoric Research Priorities for the Southwestern National Forests[1]

Thomas R. Cartledge[2], Patricia L. Crown[3], Jeffrey S. Dean[4], Suzanne K. Fish[5], David M. Johnson[6], and Steadman Upham[7]

INTRODUCTION

In this chapter, key prehistoric research themes are discussed in both applied research and management frameworks. The purpose of this chapter is to elaborate upon the research themes identified and discussed by Upham (this volume), and to provide specific research recommendations regarding the planning and implementation of a long-term program of archeological research on the National Forests of the Southwestern Region. To accomplish this task, the chapter is divided into five sections. In the first section, the relationship of research programs to the mission of the Forest Service is discussed. In addition, a discussion is provided that seeks to relate key prehistoric research themes to integrated research designs and to the broader issues of compliance with federal cultural resources laws and regulations.

In section two, a summary of key research topics is provided. This discussion is tied to an earlier effort to define archeological research themes for the National Forests (Cordell, Schiffer, and Upham 1983). Specific research problems and recommendations are presented and discussed in section three. These specific problems and recommendations are derived from Upham's chapter, and are intended to serve as examples of how key prehistoric research can be accomplished using archeological data from the Forests. We recognize that the program of research we envision must be flexible, and must be capable of being implemented in a variety of different areas with diverse resource bases. To illustrate both the promise and the potential difficulties of our approach, two discussions are provided in section four that describe the archeological resource bases of the Lincoln and Santa Fe National Forests in relation to the key prehistoric research themes identified by Upham. In the final section of this chapter, we provide a set of recommendations for implementing our research program that describes staffing and equipment needs, budgeting requirements, the role of contract research, and time frames for achieving the research objectives.

ARCHEOLOGICAL RESEARCH AND THE NATIONAL FORESTS

It is axiomatic that archeological research must proceed in tandem with the development of regional research designs. The development of research programs on the Forests must develop in accordance with this fundamental scientific principle, being in lockstep with the development of comprehensive, integrated research designs. To this end, the research discussed in this chapter and in that by Upham (this volume) must proceed in conjunction with prioritized research programs that follow from the preparation of integrated research designs. Such research must also be consonant with the goals of the comprehensive Forest Plan, and should articulate with the research design at the level of cultural concept, geographical limit, and chronological limit. Moreover, planned archeological research needs to

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[1] Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2] Thomas R. Cartledge is Forest Archeologist on the Santa Fe National Forest, Santa Fe, NM.

[3] Patricia L. Crown is Assistant Professor of Anthropology at Southern Methodist University, Dallas, TX.

[4] Jeffrey S. Dean is Professor of Anthropology at the University of Arizona, Tucson, AZ.

[5] Suzanne K. Fish is an archeologist with the Arizona State Museum, University of Arizona, Tucson, AZ.

[6] David M. Johnson is Forest Archeologist on the Lincoln National Forest, Alamogordo, NM.

[7] Steadman Upham is Associate Dean of the Graduate School and Associate Professor of Anthropology, New Mexico State University, Las Cruces, NM.

be undertaken within the constraints of existing study units, operating plans, and management units. It is recognized, of course, that the character of the archeological data bases that are unique to each of the Forests in the Southwestern Region will determine the kinds of research that can be undertaken. The integrated research designs should speak to this issue, as the success of any research program is directly related to the adequacy of the data base that is employed.

Research on and management of cultural resources requires a recognition that the allocation of cultural resources is fundamental to both enterprises in a multiple-use context. Allocation, however, requires high-quality data upon which critical decisions regarding the disposition of cultural resources can be made. At present, the existing archeological data bases (site records, artifact inventories, site reports, etc.) of the Southwestern Forests are inadequate to undertake a comprehensive allocation program. Serious deficiencies exist in areal coverage, and key descriptive information on variability in site types is uneven or absent. The results of this lacunae are seen most profoundly in archeologists' inability to predict the location of specific kinds of sites given sufficient descriptive parameters and prior conditions (Cordell and Green 1984). Consequently, it is not yet possible to enter into an allocation strategy that would permit the identification of specific site categories and allocate them for highly selected uses (e.g., conservation, research, and public interpretation).

To remedy these deficiencies, a comprehensive program of inventory and evaluation must be undertaken with the specific intention of providing critical baseline information on the nature, extent, and diversity of archeological resources on the National Forests of Region 3. Evaluation of existing data in the Forest Service site files should begin immediately in an effort to determine where archeological survey needs to be undertaken and what survey intensities should be used. Moreover, all existing site information needs to be computerized in a standardized format so that central access to survey data is possible. Until both of these objectives are met (comprehensive inventory survey and computerization of site files), it would be unwise to pursue a strategy by which cultural resources were allocated to any specific category of use.

A beginning point in the development of an allocation plan is the preliminary work of Spoerl and Tainter (1983). Their research, and that of the other participants in the 1982 and 1983 cultural resources symposia (Green and Plog 1983; Cordell and Green 1984), should be consulted to identify management and research needs from the past. These documents are now in need of revision, but their use will ensure the development of institutional memory with respect to this planning effort, and will permit a more coherent developmental approach to cultural resources management on the Forests. It is important to point out that the underlying theme of Spoerl and Tainter's work is that allocation cannot proceed in the absence of comprehensive long-range planning coupled with sufficient funding to permit archeological resources to be allocated for research, conservation, public interpretation, and a variety of other uses.

The program of research outlined here and in Upham's chapter requires that the Forest Service accommodate the discipline of archeology and those fields that support it (dendrology, palynology, materials science, geomorphology, etc.) within the structure of the Research Stations presently in existence. Funding for this enterprise is also required to ensure continuity over the long term. It should be recognized that investing in this kind of research program will be of long-term benefit to the Forest Service in that it will provide critical assistance in the following areas:

a. Compliance with federal cultural resources laws and regulations, especially as they relate to the broader mandate of the National Environmental Policy Act, the National Historic Preservation Act, the Archeological and Historic Preservation Act, Executive Order 11593, the Archaeological Resource Protection Act, and all of the associated regulations that serve to guide the implementation of the above legislation;

b. Establishment of a comprehensive allocation strategy that is defensible in light of the non-renewable character of the archeological record, the multiple-use mandate of the Forest Service, and the research needs of the professional archeological community;

c. Preservation of a large portion of the archeological record for future generations of Americans, thereby contributing to development of an historical persona for Native and Anglo-Americans alike; and

d. Development of a program of public interpretation to allow for education through participatory archeology, displays, and site reconstructions.

In the following sections of this chapter, we summarize current research directions and identify specific research problems that can be addressed using archeological data from the Southwestern Forests.

SUMMARY OF RESEARCH TOPICS

Archeology as a discipline possesses neither a unified body of theory nor a unified notion of key research topics. The Southwest is a large region of great natural and cultural diversity. The research interests of archeologists working in the area reflect this diversity in the studies undertaken and the methods used. It is not possible to arrive at a consensus of important prehistoric research questions for the

Southwestern Forests. Not only do the archeologists working at any one point in time differ over relevant questions and applicable methodologies, but interpretive paradigms and recovery techniques change at a rapid pace. Any research questions identified today may not be considered relevant in a year. In a discussion of "Forest Research Topics" arising from the Cultural Resources Allocation Conference held in May 1982, it was stated that, "In each case where a permit is requested to excavate a site on a National Forest, or where data recovery is proposed in response to a management or compliance requirement, archeologists will be expected to develop research designs that relate in positive ways to one or more of the Topics" (Cordell, Schiffer, and Upham 1983: 10). We argue to the contrary: that the Allocation Conference report reflects the particular biases of the six conference participants, and should not be considered a laundry list of the only, the most relevant, or the most appropriate research problems for prehistoric sites in the National Forests. Innovative approaches and unusual research problems will be more appropriate for particular locales and should not be excluded from consideration by the Forest Service because they are not outlined here.

Furthermore, and in response to a question posed at the conference, it is not possible to outline a program for research at prehistoric sites on the National Forests that will produce a complete record of the prehistory of all populations ever inhabiting those areas. If we had the capability to do this it would have been done. The data recovery, documentation, and interpretive techniques needed to perform such a desirable end are not available to us now, and hence there is a need for continuing methodological studies, interaction among archeologists with differing points of view, and resource conservation.

An integrated research program on the National Forests is unquestionably needed, but a reasonable goal of such a research program cannot be the completion of all archeological work on the Forests nor a record of prehistory that is "as close as we need." The goal of such a program should be to integrate research on the Forests and ensure optimal allocation of resources in light of the current and future archeological potential of those sites to address relevant research concerns.

Recognizing this, we can provide a summary of many, but certainly not all, current research topics for prehistoric resources. Upham's paper (this volume) provides a detailed examination of research relating to the development and collapse of social systems (agriculture, demography, settlement, labor, economy, and environment), site dynamics (formation processes, transformation processes, and observer bias), and interpretation issues (adaptive diversity, visibility, and chronometric dating). These are all relevant and significant research questions, but will not be discussed here in detail. The reader should consult Upham's paper for details on these questions.

The earlier effort by Cordell, Schiffer, and Upham (1983) provided even greater detail on these and additional questions. An outline of their suggested research themes and the research and development efforts they recommended for approaching each topic is provided below. The reader should consult the original volume for greater detail and justification for each topic.

I. The Rise and Fall of Civilizations

a. Sedentism

1. Refine methods for determining the degree of sedentism in the archeological record.

2. Undertake simulation models of hunter-gatherer behavior.

3. Delineate resource distributions and Archaic scheduling activities.

4. Evaluate the demographic consequences of sedentism, the material correlates of sedentism, and the use-life of structures.

5. Assess the distribution, function, and size of various types of storage facilities.

6. Determine whether we can evaluate population size on the basis of storage facilities.

b. Large Settlements and Complex Systems

1. Test theoretical models for the evolution of sociopolitical complexity involving "causal" variables.

2. Assess the extent of productive specialization and the role of specialists in society; evaluate various means of examining specialization, and changes in technology and style accompanying complexity.

3. Develop site occupation histories and paleoenvironmental reconstructions.

4. Evaluate status differentiation within sites through studies including the examination of burial practices and diet/access to food.

5. Examine restriction of access to information (sacred/esoteric) in part through spatial distribution of styles.

6. Determine the role of small sites in sustaining populations at large sites.

7. Assess the relative importance of environment as opposed to social relationships in determining the location of large settlements.

c. Agriculture

1. Determine the relative productivity of various Southwestern cultigens.

2. Determine whether species believed to be wild were actually manipulated and/or cultivated by Southwestern populations.

3. Evaluate the determinants of agricultural intensity and the labor requirements of various cropping strategies.

4. Assess what can skeletal populations can tell us about the diet and health of Southwestern populations.

5. Determine what early prehistoric northern Mexican agricultural strategies can tell us about the introduction of agriculture in the Southwest.

6. Refine our models of climatic change, and our methods of chronological control over the dating of changes.

7. Delineate the material correlates of various types of agricultural practices.

d. Regional Organization

1. Reevaluate existing models of the spatial distributions of sites.

2. Develop spatial models for societies at different levels of complexity.

3. Reassess site-function interpretations.

4. Map the distribution of natural resources in the Southwest.

5. Map the distribution of rare or unique architecture in the Southwest.

6. Map the distribution of agricultural features and evaluate the labor investments made in each kind of feature.

7. Undertake ethnoarchaeological research on task group composition in societies at different levels of complexity.

e. Protohistoric/Ethnohistoric Periods

1. Search archives for information on Southwestern groups during historical time periods.

2. Assess the response of ethnographic groups to foreign intrusion.

3. Study refugee sites on the Santa Fe National Forest.

4. Examine archives and archeological data on the construction of churches/missions, and the sizes of harvests, fields, and storage facilities in historic sites.

5. Assess the role of exchange during the ethnohistoric period.

6. Evaluate how the development of an ethnic identity in the Southwest was influenced by the presence of a foreign power.

7. Estimate population during the protohistoric and historic time periods.

II. Environmental Change

a. Continue studies in sedimentology, hydrology, geomorphology, and palynology.

b. Develop new techniques for paleoclimatic reconstruction, especially using packrat middens and plant opal phytoliths.

c. Inventory and evaluate photographic archives, and documents relating to paleoclimate.

d. Assess past species diversity using archeological materials.

e. Reevaluate existing techniques of paleoclimatic reconstruction in terms of formation processes, particularly focusing on pollen analysis.

f. Assess rockshelter deposit formation and the effects of human presence in rockshelters.

III. Abandonment and Depopulation

a. Evaluate anthropological models for abandonment/collapse.

b. Develop methods to identify low-visibility social groups in the archeological record.

c. Develop methods to evaluate population changes through time.

d. Determine conditions under which migrations occur.

e. Evaluate collapse of regional systems and disappearance of boundary-maintaining devices.

f. Refine methods of determining homogeneity and heterogeneity within skeletal populations.

g. Study agricultural techniques at large settlements, and soil and fuelwood depletion.

h. Examine collapse as part of the normal developmental trajectories of complex systems.

IV. History of Land Use

a. Catalog documentary materials pertaining to vegetational changes.

b. Develop simulation and experimental models of land-use histories.

c. Compile data on evolutionary trajectories of modern biotic communities.

d. Determine prehistoric distributions of animal species.

e. Study land changes relating to agricultural practices/nutrient requirements of Southwestern crops.

f. Examine land-clearing for construction, fuelwood, and fields.

V. Chronology

a. Reevaluate dating techniques.

b. Develop techniques to date artifacts and ecofacts directly.

c. Develop techniques to identify formation processes for contexts from which datable materials are taken.

d. Date annual plants rather than wood wherever possible.

e. Determine average age of downed wood pieces in woodlands.

f. Refine archaeomagnetic dating curves for the Southwest.

g. Evaluate the effects of forest fires and fire management on dating materials.

h. Develop local obsidian hydration rates.

i. Reevaluate the number of well-dated sites in the Southwest.

j. Determine if thermoluminescence dating is useful for the Southwest.

k. Determine the use-life of various artifact categories.

l. Evaluate relative dating techniques.

VI. Unidentifiable Sites

a. Date unidentifiable sites.

b. Assess the distribution of unidentifiable sites across the landscape.

c. Map territories used by known groups.

d. Evaluate exchanges in material goods that may contribute to confusion in identifying the ethnic identity of site inhabitants.

e. Evaluate differences in lithic reduction technology of Puebloan and Archaic groups.

VII. Artifact Studies

a. Evaluate and refine techniques for determining sources of raw materials used by Southwestern populations.

b. Refine techniques for identifying manufacturing loci.

c. Evaluate ceramic vessel properties.

d. Plant experimental gardens using various techniques, and measure labor investment in planting and harvesting crops and harvesting wild plants.

VIII. Formation Processes

a. Investigate the effect of formation processes on inter-assemblage variability.

b. Improve site discovery techniques.

c. Evaluate various kinds of impacts on sites.

d. Experimentally study sherd breakage, and ecofact formation/preservation.

e. Evaluate formation processes of deposits (floors) used most often in interpreting past societies, and techniques for recovering information and artifacts from such contexts.

The research themes outlined in Upham (this volume) and Cordell, Schiffer, and Upham (1983) do not pretend to exhaust all research themes for prehistoric archeology. First, they deal almost exclusively with the formation and collapse of sedentary agricultural societies in the Southwest. Hunting and gathering groups are discussed primarily as they relate to the shift to sedentary/farming life, to interactions with contemporaneous sedentary/farming communities, and to resilient responses by farming communities to changing natural and social environments. Questions concerning PaleoIndian and pre-agricultural Archaic adaptations are not specifically addressed. Many of the general topical areas presented by Upham are relevant to such research, although not outlined as such.

Most of Southwestern prehistory was characterized by populations with hunting and gathering economies, and yet considerably less is known about these populations than about later farming groups. Research is needed to define the nature and extent of PaleoIndian and Archaic exploitation of Southwestern environments. Many PaleoIndian and Archaic sites are deeply buried and improvements are needed in techniques for locating and recording such sites. Archeologists are increasingly recognizing and excavating Archaic locales, and this research has led to controversy over the traditional view that Southwestern Archaic hunting and gathering populations can and should be differentiated into "cultures." These issues illustrate the need for reevaluating existing models of PaleoIndian and Archaic adaptations. Examples of research issues that should be addressed are:

a. Develop means to differentiate PaleoIndian and Archaic sites from lithic scatters associated with farming groups.

b. Delineate the distribution of prehistoric floral and faunal resources, and scheduling of foraging activities.

c. Evaluate the relative appearance of sedentism

and cultigens in various environments of the Southwest.

d. Determine how populations in different environments within the Southwest responded to the introduction of cultigens.

e. Assess the merits of defining Archaic cultures within the Southwest (e.g., Irwin-Williams 1967), as opposed to adopting a model of overarching uniformity in material culture (Huckell 1984) prior to the introduction of agriculture

f. Assess how stylistic boundaries were maintained in PaleoIndian point types, and what the widespread distribution of common styles indicates about intensity of interaction and social boundaries.

An important aspect of the development and collapse of social systems is the level of community organization and the presence of mechanisms promoting social integration. Two means of approaching the degree of intra-community organization include the examination of site structure and of ritual integration. The structure of sites at any point in time can tell us much about how the inhabitants of that site interacted with one another and organized the use of space for secular versus sacred or community versus elite activities. Changes in the use of space through time reflect changes in social structure and shifts in the integrative levels of various populations. The role of ritual as an integrative mechanism can be explored through the definition of specialized ritual architecture and assemblages within sites, the examination of burial offerings, and the distribution of particular decorative motifs in ritual contexts. Topics that should be addressed include:

a. Determine how populations organize the use of space for sites of different functions.

b. Evaluate where various activities take place within and outside of sites.

c. Map the size, frequency, and location of facilities used in integrative rituals.

d. Assess what the information in (c) tells us about the sizes of groups served by these rituals, and the types and levels of social integration present in the populations inhabiting the site or community.

e. Delineate the information content of ritual iconography, and rock art.

f. Determine how changes in the nature of ritual architecture/assemblages through time reflect changes in the sizes of populations served by these facilities and the portion of the society with access to esoteric knowledge.

Hundreds of additional research problems could be outlined, but this document provides what we feel is a good sample of research needs. In the following section, four of the research problems outlined above are reviewed in detail, and recommendations are developed for implementing such research.

RESEARCH PROBLEMS AND RECOMMENDATIONS

The Development and Collapse of Social Systems

Subsistence

Synchronic and diachronic aspects of prehistoric subsistence have been major topics in Southwestern archeology since its inception. Subsistence has received the greatest sustained attention among non-typological concerns due to the economic focus of much previous and current method and theory. The following problem areas require investigation of extra-cultural potential and constraint, as well as culturally-patterned strategy and response.

The Earliest Cultigens.--The addition of cultigens to existing subsistence orientations accelerated the rate of change in Southwestern societies and supported populations responsible for the bulk of the visible archeological remains. Timing of the introduction of crop plants, and particularly of the staple maize, has been fairly well bracketed in several Southwestern regions (Simmons 1986; Upham et al. 1987; Fish et al. in press). In spite of well-founded dates earlier than the 500 B.C. introduction suggested in an influential model (Berry 1982), questions persist as to the role of cultigens in the period following their appearance. Such questions include the roles of choice and compulsion in trends toward agricultural reliance, and the place of sedentism in this process.

Since identified remains of the earliest transition are few, effort must be concentrated on discovery. In regions yielding the earliest cultigens, there is minimal knowledge of subsistence patterns immediately preceding introduction. The chronological imprecision of projectile point styles is a difficulty to be overcome in locating appropriate sites. Stratified situations with good preservation such as caves have been critical in the past. However, Simmons' (1986) recovery of early maize evidence in open sites marked by low numbers of lithics is cautionary. Subsistence patterns spanning the transition must be acquired to model variation in initial adoption and degrees of reliance. Settlement frameworks are essential for placing early dates in a meaningful context.

The following sequence is suggested for initiating research: (1) inspection of existing site records; (2) revisitation of the most promising sites; (3) excavation of a stratified sequence or an unstratified series for refinement of artifact chronology; (4) revisitation of additional likely sites and likely locations; and (5) selection for more intensive study of representative sites spanning the transition. In view of the poor artifactual diagnostics, cultigen

presence may be a relevant indicator. Groundstone washes for pollen and botanical analyses of hearth and pit contexts should be undertaken. Direct dating of cultigen remains by conventional or tandem accelerator methods are essential. Coprolite, teeth, and human bone analyses should also be undertaken as possible.

Resource Mixes.--The issue of relative resource dependence forms a continuum with concerns surrounding the appearance of cultigens. Some evolutionary schemes order prehistory according to sequential dietary emphasis. Resource combinations resulting from subsistence strategies in particular times and places provide the bases for evaluating not only these broad chronological trends but also the extent and significance of synchronic variety.

Preagricultural societies constitute one subset of study. PaleoIndian subsistence is associated with mobile hunting of large game. The remains of large game species are often visible archeologically, and have therefore often been studied. Research should be equally directed toward alternative site types of the period and their subsistence records. Regional patterns of Archaic resource use across the Southwest are tenuously linked to arrays of utilized species. The rarity of preagricultural sites with potential for subsistence recovery is such that promising cases should be given high priority for intensive study.

Fluctuating resource emphases during agricultural times have been correlated with such factors as population growth, climatic oscillations, and long-term environmental trends. More recently interest has grown in the existence of differing economic orientations and mutualistic relationships among contemporaneous populations (Upham 1988). Realistic evaluation of resource mixtures depends upon the efficacy of comparative techniques. Quantification of subsistence remains is itself problematical. Techniques must be standardized and equivalence in sampling addressed in order to establish reliable contrasts. Additionally, sampling must be coordinated in the quantitative comparison of artifacts, facilities, or space pertaining to resource use.

In single National Forests or in adjacent Forests, contemporary settlements of different cultural affiliations provide an opportunity to examine cultural as well as environmental influence on resource mixes. For cultural segments in similar environments, equivalent sampling can be instituted and the results compared. Incorporation of agricultural and nonagricultural products in a subsistence mix can be then evaluated in terms of environmental opportunities and limits. In addition, culturally-shaped components of strategy affecting this balance should also be illuminated by contrast. According to time, money, and investigator interest, such comparative study could encompass settlement pattern, artifactual distributions, biological remains, catchment shape, or other aspects.

Implements and Facilities.--Nonagricultural implements and facilities of subsistence are spatially arrayed in such a way that they may be treated in the focused study of sites, or are so widely dispersed that they require special recovery methods. On the other hand, the remains of agricultural activities cover substantial portions of the landscape in a wide range of densities. Agricultural technologies and their success provide basic insights into the adaptations of more dense and numerous prehistoric populations and thus may furnish environmental lessons for the present.

Former agricultural fields may be marked by remains of features constructed to enhance crop habitat through water or soil control. These may be accompanied by temporary habitation or storage structures, fieldside processing facilities, and specialized artifact assemblages. These locations also contain botanical remains for identifying crop types and agricultural practices. Such remains are often so widespread that they are difficult to avoid in modern land use.

While identification and preservation of agricultural facilities must continue as a routine Forest management activity, initial studies should be directed toward areas in which other elements of settlement pattern are well recorded. Implements and facilities provide minimal understanding of overall subsistence systems, organization of production, and labor allocation, unless viewed in a settlement context with chronological association (e.g. Crown 1984; Fish et al. in press). A particular research need is new methods of systematic recording able to encompass the variety of forms and distributions of agricultural remains on Southwestern Forests.

Health, Diet, and Nutrition.--Nutrition and health of prehistoric populations is a key element for gauging one kind of success in subsistence strategies, understanding choices among alternative strategies, and assessing the implications of shifts in economic lifestyles. Precontact history of health and diseases can be known only from archeological evidence. The origin and development of New World pathogens and the impacts of Old World types are of particular significance.

Ongoing archeological investigations generate continual data, but many research problems might be approached through existing collections from Forest lands or adjacent areas. Directly relevant materials for examining variables of diet, nutrition, and health are often in the form of human remains. Examinations of bone, teeth, and mummified tissues are crucial to establishing data on stature, nutrition, trauma, mortality, and other population measures, prehistoric medical procedures, and cultural practices affecting the physical states of individuals. Investigative parameters in these instances must be developed in concert with the concerns of Native Americans.

Health and diet outcomes of the transition to agriculture are major current issues. Baseline

studies of nonagricultural populations are necessary. Exciting new methods that assess dietary ratios from bone and coprolite remains offer quantitative estimates of dietary elements. Coprolite studies also offer insight into seasonality of diet, parasitic infections among settled populations, and other factors.

Catchments.--The term catchment is used here in a broader sense than the area sustaining subsistence needs for a single site. Catchments can be defined at a number of increasingly inclusive scales or for highly mobile groups. It is a concept that aids in modeling the acquisition of multiple subsistence resources for any analytical unit of population. Catchment study requires knowledge of distributions of resources and variables affecting resources as well as evidence for specific uses, and extractive and productive activities of the populations being studied. Catchment studies further have implications for intergroup relationships in that they partition the landscape into overlapping, intersecting, or mutually-exclusive human territories.

Catchment investigations are particularly appropriate for Forest research for several reasons. Forests encompass among the least disturbed natural areas, and are suitable analogs for prehistoric biotic conditions and resource availability. Forests continually amass biotic data useful for backgrounds to such study, and possess the technology for their measurement and manipulation. Existing site inventories may be inadequate for some purposes, but could contribute toward data sets for broad studies and permit selection of locations for more focused ones.

A class of catchment study capitalizing on Forest information would be that concerning prehistoric wood use. Catchment areas for firewood, construction, and other uses are known in detail for few areas, although availability or depletion of supplies has been recognized as a potential factor influencing sedentism and specific site locations. A recent Chacoan study by Betancourt et al. (1986) illustrates the organizational aspects of unusually expansive catchments in complex societies. Forest data would be of great benefit in modeling source, labor, transport, sustainability, and many other aspects of prehistoric catchments for wood resources.

Environment

Variability in Time and Space.--While knowledge of the present environments of the National Forests is indispensible to understanding past human behavior, it must be remembered that natural systems are not static. Consequently, modern conditions cannot be used as direct analogues of conditions that confronted the prehistoric human inhabitants of the Southwest. Paleoenvironmental variability must be reconstructed to a level of refinement at least equal to that of the archeological record in order to understand human behavioral interaction with past environmental fluctuations. Recent environmental reconstruction on the Colorado Plateau (Dean et al. 1985, Euler et al. 1979, Gumerman in press) can serve as a starting point for paleoenvironmental research on the Forests.

Two types of environmental variability that represent end points on a continuum of variation are distinguished. Low frequency process (LFP) variability is due to natural processes with periodicities more than 25 years long. High frequency process (HFP) variability is caused by natural processes with periodicities of 25 years or less. The former are recognized chiefly through geomorphic studies of Pleistocene and Holocene alluvium and through palynological analyses of geological deposits. HFP variability is perceived primarily through dendroclimatic analyses of climate-sensitive tree-ring chronologies. These techniques provide information on several important aspects of environmental variation, including amplitude, trend, duration, and temporal and spatial characteristics. These aspects of environmental variability, singly and in combination, can be associated with a range of behavioral responses that can be recognized in the archeological record (Plog et al., in press).

A conceptual model of behavioral adaptive systems (Dean, in press; Dean et al. 1985) specifies the manner in which environmental variability combines with demographic variation and sociocultural factors to trigger systemic change in adaptive systems. While few would assign primacy to environmental variability, it also is true that human behavior in the Southwest cannot be adequately understood without detailed knowledge of past environmental fluctuations. The Southwestern Forests possess the potential for meaningful research into this topic.

Many data needed for this type of research are already in hand. Existing Forest Service information on soils, vegetation, and fauna could be used to calibrate variability in modern conditions with measures of past environmental variations. Many suitable areas exist for geomorphic studies comparable to those achieved by Karlstrom (in press; Karlstrom and Karlstrom 1986) on the Colorado Plateau. Such research would involve detailed stratigraphic analyses of alluvial exposures accompanied by independent dating of the deposits. Analyses of pollen profiles in the many lakes and bogs of the Forests would provide unparalleled data on LFP vegetational fluctuations from the end of the Pleistocene to the present. Palynological and geomorphic estimates of effective moisture and crop production would provide crucial data on agricultural potential through time and space.

A wide variety of HFP variables could be reconstructed through dendroclimatic analysis. Much of this research already has been accomplished or is in progress at the Laboratory of Tree-ring Research at the University of Arizona

(Dean and Robinson 1977, 1978). The primary need at present is to update the climate-sensitive tree-ring chronologies, most of which end at around 1970, through recoring of the original living trees and adding new trees to the data network. An especially promising opportunity exists to contribute to an ongoing study of extremely long tree-ring chronologies suitable for reconstructing several climatic variables over the entire western United States for the last two millennia. Much of the chronology network is already in place: there is a series of more than twenty stations ranging across the Great Basin and the Southwest. Augmenting this network would provide a data grid of unprecedented breadth and depth for the reconstruction of climatic variability throughout the western U.S.

Implementation of the environmental research outlined above would require the services of a project manager who would supervise the activities of Forest Service researchers and cooperating scientists from outside agencies. Reconstruction of LFP environmental variability would require one or more alluvial geomorphologists and the services of several outside organizations to provide the chronometric determinations necessary for dating the alluvial units. Pollen analysis would involve the selection of loci to be cored, execution of the fieldwork, analysis of the samples, and comparison and collation of the resulting pollen curves with one another. HFP environmental reconstruction could best be accomplished through contracts with the Laboratory of Tree-ring Research, which already has completed much of the necessary work. Minimally such an undertaking would involve the collection of cores from trees in selected sites throughout the Forests, data processing, and merging the results with preexisting chronologies to produce the data network. Standard dendroclimatic analyses then would be used to reconstruct various climatic variables such as temperature, precipitation, PDSI, runoff, and others. Comparison and collation of the data from all paleoenvironmental analyses would fall on the Forest Service Project Manager, who would require the assistance of specialists to produce graphic and cartographic syntheses of the relationships among all measures. The result would be detailed knowledge of paleoenvironmental variability across the Southwest for the last 2000 years. Such data not only would benefit archeologists in their attempts to explain past human behavior, but would also be invaluable for studies of floral and faunal variability, forest dynamics, geomorphic processes, and many other natural phenomena.

Resource Data Base.--Human resource data bases for each Forest do not in themselves represent products of problem-oriented archeological research. However, compiled to meet archeological needs, such documents would enhance research capabilities of Forest and non-Forest Archeologists alike. These data bases could be assembled to document distributions of resources from archeological and ethnographic contexts, to describe the current environment from the standpoint of human needs, and to identify historic changes from earlier conditions.

Forests currently monitor and describe climate, physical aspects of the environment, wildlife, and vegetational patterns for management and planning purposes. Additional observations pertinent to archeology might be incorporated through communication between archeologists and other Forest personnel. Ancillary studies to assemble specific archeological data are also necessary. These could include edible and craft-material species, mineral deposits, lithic sources, cave locations, and hydrological, soil, or climatic variables affecting prehistoric and historic agriculture. Locational data on such factors would be critical in catchment analyses and in interpreting subsistence strategies as outcomes of multiple choices among scheduling, labor allocation, cultural preference, risk estimates, and other factors.

Ethnographic Data Base.--Ethnographic data bases could be compiled in conjunction with ones for resources or separately, although both are essential for many research topics. Literature resources exist for most Forests and may pertain to observations and descriptions prior to the memories of living members of traditional groups. Desirable information may be scattered widely beyond purposeful ethnographic accounts in the remarks of explorers, colonists, military personnel, and temporary visitors. Archival research is a valuable means of access to less familiar sources.

Ethnographic data pertaining to subsistence is of management and planning as well as archeological concern, since Native American and traditional groups may currently draw upon Forest resources. In this sense, cognitive mapping of resources by such groups would serve simultaneous information needs. As discussed under a section on Native American heritage, such accounts should be considered at the discretion and direction of the groups in question.

Elicited, volunteered, and literary accounts of resource use are each unique in articulating choice, strategy, preference, and other mentalistic correlates of resource use. Furthermore, such accounts offer optimal analogs for travel, transport, labor costs, scheduling, exchange practices, and other behavioral components of susbsistence systems. Persisting patterns of traditional practices could be integrated with experimental, interpretational, and recreational programs. Examples are demonstration gardens of traditional crops or nature trails emphasizing aboriginal resources and their use.

Site Dynamics

The topics of site formation processes, transformation processes, and observer bias have been treated in some detail by Upham (this volume)

and by Spoerl (this volume). These discussions are based on the work of Upham and Green (1988), and on a host of recent publications following the scientific genre established by Michael Schiffer. Increasingly, archeologists are treating the issues of site formation processes as central elements in the interpretation of both survey and excavation data. We encourage reconfirmation of the research goals identified in the proposal submitted by Upham and Green in 1982 to the National Science Foundation. Resurrection of the research program identified in that proposal, especially with respect to measuring the effects of logging, machinery, grazing, wild and prescribed fires, recreation, and access, should be a top priority of the Forest Service. In addition, research should be implemented to realize Upham and Green's goals regarding the biases introduced into survey records due to differing survey standards, variation in site recognition, site recording, and site collection.

At the time that Upham and Green completed their NSF proposal, the idea of a landscape approach to archeological survey was poorly developed. Consequently, the proposal was structured around the traditional "site" concept, employing the definition(s) used by the Forest Service. Given the recent developments in the landscape-based approach, and the explicit emphasis on that methodology by Sullivan (this volume), Upham and Green's NSF proposal should be revised to reflect these new methodological advances.

A final area of concern is directly related to the process of site formation. Experimental approaches to this problem as defined by Fosberg et al. (this volume) should be undertaken to evaluate potential variability in the occupational and depositional histories of both real and manufactured sites. In addition, historical sites should be used, especially those for which detailed historical documentation exist, to reconstruct the occupational history of specific sites. Fine-grained studies of depositional stratification need to be undertaken on these sites, and detailed comparative and quantitative studies of the artifact assemblages should be completed. In these studies, historical documentation should be used to establish parameters of the occupation, particularly with respect to demographic issues and to details of functional differentiation among structures and use areas of the site.

INTERPRETIVE ISSUES AND TECHNICAL RESEARCH

Chronology

Few archeologists would deny that refined chronological control is essential to their efforts to characterize and understand past human behavior. Indeed, the kinds of research questions that currently occupy archeologists' attention cannot realistically be addressed without such control. A wide array of such questions is embodied in the various aspects of the general issue of the development and decline of social systems outlined above. A successful attack on this problem rests, minimally, on reasonably secure and exact knowledge of the dating of past sociocultural events, temporal relationships among communities, and temporal relationships between activities that take place at residential loci and activities that occur elsewhere. Unless the material remains of past human activities can be accurately and precisely dated, it will be impossible to construct the refined, high-resolution chronologies necessary to produce the required knowledge. Undeniably, then, chronology remains a key research topic for archeology in general, as well as for archeology on the National Forests.

An integrated attack on archeological chronology on Southwestern Forests involves two primary objectives: (1) refinement of independent dating methods; and (2) dating archeological sites that lack independent chronometric assessments. Attainment of the latter depends largely on achievement of the former.

Independent Chronometric Dating

A variety of independent dating techniques have been developed over the past 75 years. These methods span a wide range of variability in terms of accuracy (ability to produce the correct date), precision (ability to replicate results), and resolution (ability to discriminate units of time). Four techniques with the potential to contribute to the above objectives are briefly described below in order of decreasing accuracy, precision, and resolution. These characterizations are followed by a series of research recommendations that apply, first, to chronometric concerns in general and, subsequently, to the individual dating techniques.

Dendrochronology, or tree-ring dating, is accurate to the calendar year, is absolutely precise in that any number of replications will achieve identical results, and is capable of differentiating one calendar year from another. These characteristics have provided Southwestern archeology with the finest prehistoric chronological control in the world. Dendrochronology in the Southwest, however, is limited to contexts that provide datable wood or charcoal.

The accuracy and precision of archaeomagnetic dating are several orders of magnitude below those of dendrochronology. Resolution is only on a scale of decades rather than years. Archaeomagnetism is applicable wherever a dated standard curve of magnetic pole movement is available for comparison. Although the Southwest is such an area, there is plenty of opportunity for refinement of the curve and the resultant dates. Limitations include the necessity for features of iron-rich clay that have been heated to a minimum temperature, and the possibility of

contamination by local anomalies in the geomagnetic field, forest fires, extraneous inclusions, and other factors.

Because obsidian hydration dating is relatively new, its chronometric attributes are poorly known. It does, however, exhibit lower ranges of accuracy, precision, and resolution than does archaeomagnetic dating. Although obsidian hydration has a great potential, inconsistent and contradictory results from controlled dating experiments testify to serious, unresolved problems. Furthermore, application of the method naturally is limited to areas in which obsidian is found. Given the methodological progress to be made and the comparative abundance of obsidian on Southwestern sites, the potential contribution of Forest Service research to obsidian hydration dating is great.

The accuracy, precision, and resolution of radiocarbon dating are so poor that the usefulness of this technique for dating materials less than approximately 2000 years old must be questioned. For material between 2000 and ca. 40,000 years in age, however, radiocarbon dating is the primary chronometric tool around the world. The advent of accelerator-mass spectrometer technology has permitted the dating of small samples, such as individual seeds and twigs, which in turn has rendered events such as the adoption of agriculture directly datable.

Three general chronometric problems could be profitably addressed through coordinated research that involved one or more Southwestern National Forests. These are as follows.

1. Currently available or augmented site survey data could be used to develop provisional site sequences for various localities within Forests or, where appropriate, for individual Forests or even the Region as a whole. It should be realized that such chronologies will be crude and subject to refinement as information accumulates. Nonetheless, such a series of relative chronologies would be of inestimable value in assessing regional aspects of sociocultural development, change, and decline. Among these topics are synchrony and nonsynchrony in local developmental sequences, interareal interaction, exchange, formal trading networks, the spatial scale of settlement and economic systems, and others. This objective could best be achieved through the development of a central, computerized data base that contained archeological and environmental information relevant to the above issues. Extreme care would be necessary to create a data base flexible enough to allow editing of the data, replacement of old data with better information, and the addition of pertinent data. Accomplishment of this goal would create a chronological information system of lasting value to the Forest Service and Southwestern archeology.

2. A coordinated effort could be made to sample and analyze or store exposed datable materials that are vulnerable to natural deterioration or human destruction. Examples are exposed wood or charcoal in prehistoric (cliff dwellings, rock shelters, and vandalized open sites) or historic (recent Indian sites, log cabins, and lumbering or mining features) contexts, and obsidian tools and flakes from contexts likely to be disturbed by human activities. Implementation of this research not only would materially enhance dating control in the Forests, it also would preserve irreplaceable and endangered chronometric resources.

3. One of the major foci of Southwestern archeology is the generation of areal site chronologies that can be used both for the temporal placement of newly investigated sites and as a basis for the investigation of the processes of cultural change and stability. These efforts commonly are hampered by the inability, due primarily to the lack of coordination and funding, to concentrate dating efforts on situations of high chronological promise. For example, contexts characterized by the unambiguous association of datable materials with temporally sensitive artifact attributes often cannot be exploited due to lack of planning for such unpredictable finds. Nevertheless, such instances are immensely important in building local chronologies, for they offer the opportunity to assign better dates to artifact attributes. Development of mechanisms to respond promptly and effectively to such fortuitous situations, collect potentially datable material and detailed contextual data, and undertake the appropriate chronometric analyses would be an achievement of significance and value far beyond the local situation. Such an undertaking would undoubtedly involve partnerships among many federal, state, and local institutions, and might stimulate an unprecedented level of cooperation and coordination among agencies involved in Southwestern archeology.

Only three of the many method-specific studies that could be undertaken are mentioned here. Rather than focus on the dating of archeological materials, these studies emphasize the development and enhancement of methods to improve the results achieved generally by the technique in question.

1. Insofar as tree-ring dating is concerned, exact dating is routinely possible on most Forests. Dendrochronological research could involve (a) dating of specific materials designed to enhance archeological knowledge; and (b) an effort to extend the master tree-ring chronologies farther back into the past to allow dating of older sites. Thus, the Forest Service could mount a project to extract datable tree-ring samples from contexts designed to amplify archeological gaps or from sites that have potential for extending the master sequences.

2. The Forest Service could make an important contribution to archaeomagnetic dating through research designed to evaluate the effects of forest fires on the magnetic character of

potentially datable features. If fires raise the temperature of buried features beyond the critical point, the resultant dates are irrelevant to the site and date, rather, the forest fire. The potential magnitude of this problem could be assessed through the comparison of sites that have been subjected to known fires with nearby sites spared by the same blaze. Alternatively, controlled burns could be used to evaluate fire effects on sites or on controlled test materials placed at different depths.

3. The greatest potential chronometric contribution lies in the domain of obsidian hydration dating. While the promise of this technique to deliver high-quality dates is great, it is beset by many uncertainties. Resolution of these problems depends in part at least on better control of the variables that affect hydration rate and on experimental tests designed to compare obsidian hydration results with those of other chronometric techniques. Both approaches could easily be implemented with the resources available to the Southwestern Forests. The proximity of major obsidian sources to the Forests would facilitate collection of raw material for investigating the physical and chemical variability of this material. Forest lands encompass a variety of environments that could be monitored over a period of years to disclose the variability in factors that affect the hydration rate. The wide range of sites in the Forests could produce obsidian samples of varying ages, degrees of exposure, and ambient conditions; these could be used to study site-context effects. Finally, the Forests possess excavated contexts in which obsidian co-occurs with dendrochronologically-, archaeomagnetically-, and historically-dated materials that can serve as standards for calibrating the obsidian hydration dating system.

Intrinsic Dating

A major theme of contemporary archeology is the study of human behavior on regional scales of analysis. It is commonly held that the operation of human sociocultural systems can be fully understood only if interactions among populations across broad areas can be described and explained. Perhaps the most vexing impediment to refined archeological analysis on large geographic scales is our inability to provide high-resolution dating of sites that lack independent chronometric determinations. Until this shortcoming is eliminated, efforts to handle the issues of regional-level interaction, exchange, and political interrelationships will founder on the inability to demonstrate site contemporaneity and to establish synchroneity among local developmental sequences. Forest Service research could make no greater contribution to Southwestern archeology than to make serious inroads into this debilitating problem.

Southwestern archeology is routinely, and accurately, touted as having the finest prehistoric chronological controls in the world. Nevertheless, the uncomfortable truth is that the vast majority of sites lack chronometric dates that allow exact temporal placement. This is particularly true of sites known only through survey, but applies also to many excavated sites. Since most regional analyses rely primarily on survey data, interspersed with information from the occasional excavated site, the chronological problem becomes acute. Given the relative paucity of tightly-dated cases, dating generally involves the use of time-sensitive attributes of objects or materials that are abundant on sites. As throughout the world, the chosen objects in the Southwest are lithic tools for preceramic types and pottery for later contexts.

The general practice is to work out sequences of change in time-sensitive attributes based on contextual and stylistic relationships, and then to calibrate these sequences against measures of absolute time, that is, independent dates. In the Southwest, three approaches to calibration have been employed. The first, developed by pioneer archeologists such as Colton, Hargrave, and the Gladwins (Colton and Hargrave 1937; Gladwin and Gladwin 1934; Hargrave 1932), involves the use of ceramic types defined on the basis of consistent combinations of technological and stylistic attributes (Ambler in press; Beals, Brainerd and Smith 1945; Christenson 1988). The second focuses on the temporal characteristics of decorative styles (Carlson 1970; Wasley 1959). The third relies on visual or mathematical seriations of individual design elements and element configurations (Plog 1980; Plog and Hantman 1986).

Most Southwestern ceramic chronologies, either type- or attribute-based, are calibrated, directly or indirectly, against tree-ring-dated points of association. In areas where such dates are lacking, other independent techniques have been used. The resolution of ceramic chronologies is a function of the interval between independently-dated points in the sequence, coupled with the rates of change in time-sensitive attributes. It should be emphasized that the dated points are not necessarily evenly spaced and that the rates of ceramic change are not necessarily constant. Resolution is augmented by reducing the interval between dated points either by adding more points or by seriating ceramic change between points.

Obviously, a myriad of interfering variables beset ceramic attribute calibration and dating. One of these is the character of various independent dating techniques, as described above. Only three of these methods - dendrochronology, archaeomagnetism, and obsidian hydration - are likely to have a resolution superior to that of ceramic attributes themselves, and therefore to be usable in calibration. The behavior of the people who produced the archeological remains introduces a host of uncertainties into the calibration and dating situations. The rate of change in ceramic attributes, for example, undoubtedly varied across time and space, even within types. Differential

use of vessels and sherds, such as for cooking, serving, storage, water transport, burial goods, wall chinking, and pottery firing, introduces nontemporal variability into the picture. The existence of heirlooms, long distance trade, and differential access to ceramic goods further perturb the situation. Behavior associated with the abandonment of residential loci, which is known to vary widely across the Southwest, also affects the ceramic component. Post-occupational natural and behavioral processes and events that impinge on sites further alter the original chronological information present at site abandonment. Finally, aspects of the present archeological situation affect dating potential. Methods for defining time sensitive attributes are still crude. Even more crucial is our general ignorance of the degree to which material on the surface of a site represents the totality of that site.

The key to resolving the calibration problem is the nature of the association between time-sensitive ceramic attributes and the materials that produce independent chronometric dates. Control of these associations in excavated contexts is vital to the assignment of accurate dates to points on the ceramic continuum. The resolution of the ceramic dating system depends on the number and distribution of such dated points. Maximizing the number and spread of such points will determine the utility of ceramic dating for regional analyses. Control of the various interfering variables is crucial to the dating of individual sites, the arrangement of these sites in the proper order, and the assignment of calendar dates to temporal units.

The Southwestern National Forests are uniquely suited to mount an intensive attack on the problem of "undated" site chronology. The thousands of sites representing a wide range of sizes, functions, ages, exposures, and environments provide a data base ideal for a systematic investigation of this problem. Ceramic attribute sequences for different areas, habitats, and site situations can be developed using available site inventory information supplemented by additional data relevant to this problem. Enough well-dated ceramic associations exist to provide a sufficient number of independently-dated points to assign initial dates to the sequences. Refinement of the chronology would involve identification of weak points, gaps, and inconsistencies that could be remedied by the excavation of sites carefully selected for relevant ceramic attributes and a high probability of containing materials suitable for independent dating. The improved chronology could then be further refined through iterations of the process until no further improvement was achieved.

Concurrently with the above chronological research, experiments relating to control of the various interfering variables could be conducted efficiently and easily with resources available to the Forests. Careful analyses of surface remains, coupled with controlled excavation, could elucidate the relationship between surface and subsurface remains, and materially improve the dating of unexcavated sites. Studies of ceramic type and stylistic attribute distributions across space and site types could reveal the nature and scale of time lags between areas and sites due to differential access to, or distance of, trade. The study of obsidian hydration outlined in the previous section should be integrated into the research proposed here. In addition to its value in calibrating ceramic chronologies, this method could be used for the direct dating of sites, both ceramic and aceramic, on whose surfaces obsidian occurs. Finally, studies of sites subjected to different postoccupational natural processes (erosion, deposition, forest fires, etc.) and human activities (logging, chaining, mining, road building, pothunting, vandalism, and a host of others) would elucidate the effects of those variables on site dating.

The chronological research suggested here represents a finite study that could be completed, at least in pilot form, in five years or less. In addition to a research coordinator, one or two specialists in ceramic analysis would be needed to perform the typological and stylistic analyses of the pottery. Another specialist would be needed to develop and operate computer programs for handling the site and ceramic data. Lacking curated site collections, carefully selected samples of sites representing a broad range of variability could be used for collection of the ceramic data necessary for seriation. Initial assignment of dates to points on the ceramic sequences could be accomplished on the basis of excavated data already available. Refinement of the ceramic chronology would involve limited excavation in carefully selected sites and the incorporation of new information from work unconnected with this project. Evaluation at several stages of the research would help assess progress, reveal problems, and identify procedural changes necessary to maximize progress. Five years into the project, it should be possible to release a provisional, high-resolution ceramic chronology that could be applied over a fairly extensive region by a variety of research projects. Such a chronology would allow a wide range of regional-scale studies that previously had been difficult or impossible to implement.

RESEARCH PERSPECTIVES FROM THE LINCOLN AND SANTA FE NATIONAL FORESTS

Archeologists in the Southwestern United States have identified and refined various local and regional cultural-developmental sequences for the prehistoric period. These cultural sequences apply to areas within the states of Arizona and New Mexico, including the eleven National Forests that make up the Southwestern Region of the U.S. Forest Service. The territories in which prehistoric cultural groups carried out their activities sometimes overlap present day National

Forest boundaries, but each National Forest also contains cultural manifestations unique to that particular Forest. Thus, the prehistoric cultural remains on each of the Region's eleven National Forests provide a unique vehicle whereby the key prehistoric topics identified and outlined by Upham (this volume) may be investigated. It is likely that cultural resource data from any of the Region's National Forests could be used to address, to some extent, any of the research topics, but given the variety of cultural manifestations on the various Forests, data from one Forest will probably be more appropriate for a particular research topic than from another Forest.

The following section examines opportunities for investigation of key prehistoric research topics from the perspective of two of the Region's National Forests: the Lincoln and the Santa Fe. By focusing upon these two Forests we do not intend to suggest that research concerning cultural developments in the prehistoric Southwest ought to be limited to these Forests. They are used only as examples of the kinds of research that might be pursued on any of the Region's Forests.

Before discussing research opportunities presented by the cultural manifestations on the Lincoln and Santa Fe National Forests, it is important to point out that only limited portions of both forests have been surveyed for cultural resources. Less that five percent of the Lincoln has been surveyed, while the figure for the Santa Fe is less than fifteen percent. Similar low figures apply to all of the Region's Forests.

There are also problems with the data bases on all Forests, which render them a less-than-ideal tool for undertaking investigations of the research topics identified by Upham. In the ten- to fifteen-year existence of cultural resource management in the Southwestern Region, the Region's site inventory form has undergone several changes. As a consequence, data from those sites inventoried in the early stages of the program are less complete than the data gathered more recently. In addition, there has been no particular principle guiding the collection of data; the inventory form provides for a limited amount of descriptive, environmental, and managerial data but without any specific focus. Thus it does not lend itself well to investigations of any specific research topic. Over the years, site inventory has been carried out by archeologists and para-archeologists with widely varying levels of experience. Often, inventory is accomplished by temporary personnel, and there is continual turnover in positions of this nature. As a result of these circumstances, there is considerable inconsistency, or observer bias, encoded into Forest data bases. How pervasive this problem is likely varies from Forest to Forest. Finally, cultural resource inventory in the Southwestern Region has been tied almost exclusively to project clearances. This linkage has resulted in very uneven coverage of the land area within each Forest, such that there are major areas on many Forests that have little or no data recorded. This is particularly true of Forests with active timber management programs. Here, we have considerable data from timbered areas at high elevations, but generally poor coverage in other areas. Despite these problems, however, it is felt that extant data bases can serve as a vehicle for preliminary sorting of sites into categories that would be useful in addressing the identified research topics.

Lincoln National Forest

The Lincoln National Forest is located in the highlands of south-central New Mexico. The Forest covers approximately 1.1 million acres extending from the Texas-New Mexico border on the south to the community of Ancho, New Mexico on the north. Included in this geographical area are three major mountain ranges: the Sacramento, Capitan, and Guadalupe Mountains. Vegetation is diverse, ranging from desert-scrub associations at approximately 4000 feet above sea level to alpine meadows and spruce-fir forests at over 11,000 feet in elevation. Two streams, the Rio Hondo and Rio Penasco, originate on the Forest and flow eastward into the Pecos River. Most smaller streams are confined to the Sacramento Mountains.

The Forest has been the scene of human activity for thousands of years, although no large aggregated villages or dense population areas seem to have developed. Archeologically, the Forest falls within the Jornada Branch of the Mogollon.

No firm evidence for PaleoIndian occupations has been found on the Forest, but it is likely that all prehistoric cultural periods from PaleoIndian through Apache are represented (Spoerl 1983). The Archaic Period is the first occupation on the Forest that has been documented. Archaic remains have been found in the Guadalupe and Sacramento Mountains, in rock shelters and on ridges, primarily in the pinyon-juniper zone. Most of the sites that have been assigned to this period were done so based on projectile point chronologies. Few absolute dates have been obtained.

Sometime prior to A.D. 700, the Jornada Branch of the Mogollon developed in southeastern New Mexico. This period is marked by the first appearance of pottery and villages, and is well represented on the Forest. Sites include small artifact scatters and rock art sites located throughout the Forest, villages in the Sacramento and Capitan Mountains, and large ring middens or fire-cracked rock features associated with artifact scatters in the Guadalupe Mountains and southern Sacramento Mountains. The villages appear to have been largely abandoned by the late 1300s or early 1400s, perhaps signaling a return to a more mobile existence.

By the 1700s or earlier, the Sacramento Mountains became the homeland of the Mescalero

Apaches, who dominated south-central New Mexico for the next 200 years. It is unlikely that the Mescaleros were responsible for the abandonment of the Jornada Mogollon villages: such an early date for their arrival has not been demonstrated.

The Data Base

Over 700 cultural resource surveys have been conducted on the Lincoln National Forest over the past 15 years. Currently, approximately 45,000 acres, or 4.1 percent of the Forest, have been surveyed. The majority of the surveys were located in commercial timber areas above 8000 ft. in elevation. These surveys have resulted in the discovery and documentation of 693 sites, all of which are contained in the computerized data base. Most of the sites date from the Jornada Mogollon period (Johnson, Fulgham, and Reed 1988).

As noted above, these surveys were conducted primarily in response to the need for cultural resource clearances for Forest Service undertakings, and do not represent a statistically valid sample of the Forest. Other shortcomings of the data base have already been pointed out. Nevertheless, this data base contains information on 693 sites and can be helpful in arriving at answers to a variety of research topics.

Research Opportunities

To date, very little research has been conducted on the Forest, outside of obtaining clearances for undertakings. Some excavations have been conducted, primarily in the 1930s (Mera 1938; Roberts 1929) and a few large surveys have been undertaken (Roney 1975; Beckes et al. 1977). These studies provide some general information and limited interpretations of sites located on Forest lands. The Lincoln, then, is in need of research to explain the cultural behavior that left the remains found on the Forest. Such research would aid in the interpretation of cultural resources for the public as well as the scientific community, and would assist in the management of this resource.

The Lincoln National Forest covers a major portion of the upland areas occupied by the Jornada Mogollon and other groups throughout the prehistory of southeastern New Mexico. The limited information available on the cultural resources of this area has severely hampered the understanding of the cultural past of this portion of the state. Research conducted on the Forest would fill in some important gaps in the overall interpretation of the cultural resources of southeastern New Mexico in general.

Upham (this volume) presented a series of key prehistoric research themes for the Forests in Region 3. For consistency, these topics are discussed below in terms of addressing some of the research needs of the Lincoln National Forest.

Agriculture and Subsistence

A variety of subsistence data are available on the Forest. Numerous rock shelters in the Sacramento and Guadalupe Mountains contain well preserved organic remains. Early dates associated with corn were obtained from Fresnal Shelter (Carmichael 1983). Other cultigens were identified there as well (Bohrer 1972). It is likely that similar remains are present in other shelters in the area, and would help to address questions concerning the adoption of agriculture or the use of other cultigens during the prehistoric period. Agricultural facilities and implements have rarely been found on the Forest. Possible erosion control or runoff diversion features were noted near some Corona Phase sites in the northern portion of the Forest (Reed 1987). Other features undoubtedly exist, but will have to await further survey to be identified.

Stuart and Gauthier (1981) noted that the variety of corn found in Lincoln Phase sites near the Forest was an older variety that may have been better suited to upland environments. This variety persisted until later periods than elsewhere in the Southwest, even though other varieties were being grown nearby in the Tularosa Basin. Further research into the types of corn grown in the area, and the implications of different varieties grown in upland areas, should be explored.

Demography

Research into population size, density, and distribution on the Forest will require further surveys and site recording guided by a statistically valid sampling design. Such a program has been proposed for the Forest (Higgins and Johnson 1987; Johnson, Fulgham and Reed 1988). The completion of the sample survey of the Forest will, however, take several years. Upon completion, the resulting data base will allow for research into demography as well as many other topics.

Settlement

This research theme must also be addressed through more controlled survey, site recording, and chronometric dating. The current level and distribution of surveys on the Forest will allow for only general statements concerning settlement characteristics (e.g., Spoerl 1983). Stuart and Gauthier (1981) have pointed out apparent shifts in the elevation of Jornada settlements in the Sacramento Mountains through time. This would have to be verified through further field research. The Jornada Mogollon occupation of the Forest has been characterized as highly mobile and resilient. Investigation into the impetus for sedentism on Forest lands would contribute to the understanding of how the Jornada Mogollon adapted to environmental and cultural pressures.

Settlement pattern studies would also help to explain the relationship between the upland sites and those located in the basins below.

Labor

Research into the organization and management of labor will be difficult to pursue for PaleoIndian and Archaic sites without considerable additional field work. Only 25 Archaic sites have been identified, and as noted above, no sites can be definitely assigned to the PaleoIndian period. Drawing information from the remaining sites will also be difficult. Most of these sites consist of artifact scatters with no associated features or structures.

Notable exceptions are the sites with midden rings or mescal roasting pits commonly found in the Guadalupe Mountains. These large fire-cracked features often exceed eight meters in diameter and can be up to one meter or more in height. A tremendous amount of rock had to be gathered and manipulated during the construction of these features. In some cases, the rocks appear to have been selected for color as well as size. Such selection, coupled with the labor invested, suggests that a great deal of management and organization of labor may have been involved.

These features are found in large numbers throughout the Guadalupe mountains and appear to span the late Archaic through Apache occupations. Research into their construction, the differences between some of these features, and the labor involved in their formation could help to identify differences in or continuity in labor organization and management through time.

Economy

Economic research promises to provide a variety of data important to the Forest. Investigations into exchange, for example, as reflected in variability in ceramic types, trace-element analysis of ceramics, or stylistic similarity and variation could help to explain the relationships between the Jornada Mogollon on the Forest and other neighboring groups. Interaction to some extent with Casas Grandes, the Mogollon areas to the west, and the Anasazi to the north is generally accepted, but the extent of the interaction cannot be determined without further research. Similar studies using obsidian artifacts, such as trace element analysis and stylistic analysis of obsidian tools, should also be undertaken. Although obsidian is not common on the Forest, obsidian artifacts have been found, and the research results could provide data on the economies of Archaic groups as well.

Environment

Paleoenvironmental data pertinent to the Forest have largely come from a few studies that have been conducted in nearby areas (see Camilli and Allen 1979). The most direct evidence comes from packrat middens in the Guadalupe and San Andres Mountains. There have been no tree ring or pollen analyses on the Forest. A research program that would provide more comprehensive environmental data would not only help to explain cultural reactions to environmental change, but would also be useful for understanding the past climate and its effects on timber, range, and the other forest resources.

Site Formation Processes

This topic is discussed in more detail in another paper in this volume (Fosberg et al.). The treatment here is limited to noting that investigations into site formation and transformation processes such as alluviation and erosion would be particularly appropriate for the Lincoln, and would help to identify the effects natural processes have on the archeological data base. Such research would aid in the discovery of sites in alluviated areas of the Forest, and help in the evaluation of the integrity of sites in areas subject to frequent erosion or other transformation processes.

Definition of Culture and Adaptive Diversity

The emerging notion that Southwestern societies developed organizational strategies that were extremely resilient and flexible to allow for adaptation to changing natural and social environments is directly applicable to the Lincoln data. Research along this line, however, will necessarily require more intensive surveys, better chronological control, and detailed investigations of sites, environmental conditions, and other factors before progress on the Forest can be made. Once the Forest data base has been expanded to include a more representative sample of the sites and there is a better understanding of the cultural landscape, this research will be highly productive.

Archeological Visibility

This research theme addresses the problems inherent in relying on large sites and elaborate architecture in interpreting past occupations. Small, low density sites comprise a major portion of the archeological record that has been all too often overlooked. The sites on the Lincoln primarily fall into this category, and present an opportunity to examine this type of cultural remain and determine its part in the overall settlement pattern. The low occurrence of large villages on the Forest provides a situation where the majority of the small sites have not been obscured or consumed by the larger sites, as might have happened had large aggregated villages formed in areas previously utilized by highly mobile populations.

Chronometric Dating

Many researchers in the Jornada Mogollon area have relied on relative dating to assign sites to the various phase sequences that have been proposed for the region. Several researchers have pointed out the problems inherent in relying on relative dates for this area (Cordell and Plog 1979; Upham 1984; Carmichael 1983, 1985; Reed 1987), and have called for more emphasis on absolute dating. Few chronometric dates have been obtained for sites on the Lincoln National Forest. As a result, the cultural sequence is poorly understood and temporal diagnostics are inadequately dated. A program for the collection of more dates is a high priority, and a limited approach to address this problem for the Forest has recently been implemented (Johnson, Fulgham, and Reed 1988). A much larger program of dating sites is necessary to adequately resolve the problem. A more refined chronology and accurate dating of sites will tie directly into the other research topics and will prove to be vital in the interpretation of cultural remains on the Forest.

The nature of the cultural resource base on the Forest limits, to a certain extent, the types of dating techniques that can be successfully applied. Obsidian is rare, and usually consists of surface finds. There is also a lack of exposed roof beams, and the nature of the structural remains on the Forest have left few suitable remains for tree-ring dates. Further excavations may yield other specimens suitable for dating.

Discussion

This brief discussion of the research topics proposed by Upham serves to illustrate how such topics apply to the Lincoln National Forest. All of the topics are important avenues of investigation directly applicable to the cultural remains found on the Forest. Some are more important than others, and many will involve overlapping studies to address adequately the questions being asked. Research along virtually any of these lines will result in important and long-awaited data necessary for understanding the behavior responsible for producing the cultural resources of the Forest, and interpreting these remains and the activities that formed them for the public. This research would also meet the need of management to know the locations and range of the cultural resource base, and to understand the importance of these remains for future generations.

Throughout this discussion, it has been apparent that two major issues continue to arise. One is the lack of adequate survey coverage for much of the Forest. This results in an inaccurate picture of the cultural past, and a failure to provide a representative sample of the cultural resources on the Forest. The other issue concerns the inability to assign most of the sites that have been recorded to a specific temporal period. By addressing these two issues in a research program, the data provided would result in a data base from which other more detailed and complex research questions can be addressed.

The nature of the current cultural resource management program on the Forest is such that most of the data needed to address the research questions will be slow in coming. Without a research program, sites will continue to be discovered, avoided, and set aside with only a basic idea of how they fit into overall cultural systems, and a backlog of unevaluated sites and vague interpretations of the past will continue to be the norm. The potential of this Forest resource to benefit the public, management, and the scientific community will not be realized. Only through a dedicated research program will cultural resource management break out of its reactive mode, and cultural resources will attain a level of recognition and importance long overdue from management and the public.

Santa Fe National Forest

The Santa Fe National Forest contains approximately 1.5 million acres, and is located in central to north-central New Mexico. It is divided into two major portions, generally separated by the Rio Grande River Valley and the present day communities of Espanola and Santa Fe. Each of the two separate portions is centered on forested upland areas that lie to either side of the Rio Grande Valley. To the east is the southernmost extension of the Sangre de Cristo Mountains, while the western portion is dominated by the Jemez Mountains. Water courses that originate in both mountainous areas generally feed into the Rio Grande River, although there are notable exceptions, such as the Pecos River, which flows southward from the Sangre de Cristos.

The cultural resource management program on the Santa Fe Forest was effectively initiated by 1977/78. To date about 200,000 acres have been intensively surveyed, although considerably more acres have been sampled to various degrees. Some 4500 cultural resource sites, most of which are prehistoric, have been formally inventoried. The resultant data have been entered into an electronic data base, although physical site-form files are also maintained. It is estimated that the entire Forest contains from 30,000 to 40,000 cultural resource sites. Prehistoric site types include artifact scatters, trails, shrines, soil/water control features, rock art, field houses, "towers," pithouse villages, and pueblos ranging from a few up to several thousand rooms. Temporally these sites range from late-middle Archaic up to the time of initial contact with the Spanish in the mid-16th century.

Archaic sites appear to have a limited geographical distribution in the northeastern portion of the Jemez Mountains along the Rio Grande and its tributaries (e.g., the Chama River). This limited distribution may be more apparent than real due to uneven survey coverage.

Following Archaic times it is generally believed by archeologists that there was a low level of human occupation in the Forest area until the latter part of Puebloan times, i.e., until the late 1200s. An exception to this is the Gallina area, where substantial occupation is recorded beginning around A.D. 1000 to 1050. The apparent lack of Basketmaker and early Pueblo occupation is almost certainly a function of inadequate survey coverage. We simply have not looked in the appropriate places.

Most known prehistoric sites on the Santa Fe Forest are moderate- to large-sized pueblos surrounded by thousands of field houses. They are located mostly on the Pajarito Plateau and on several large mesas in the southern portion of the Jemez Mountains near the Jemez River. These sites are representative of late Puebloan developments (i.e., post A.D. 1250). An additional substantial portion of the known prehistoric sites on the Forest are in the northern reaches of the Jemez Mountains in the Gallina Culture area. Characteristic sites here are small, dispersed villages containing various combinations of pithouses, small surface structures, and "towers." A few cliff dwellings are present in the area. Dates for Gallina occupation range from about A.D. 1000 to 1250.

Cultural manifestations located within the Santa Fe Forest can provide data relevant to virtually all of the key prehistoric research topics identified by Upham (this volume), although the particular manifestations and remains on the Forest can be used to address some of the topics more appropriately than others. Actually the treatment of these topics as separate areas of research is largely artificial and heuristic. Human behavior occurs within cultural-systemic contexts, and although one can define economy and technology, for example, as separate elements for purposes of analysis, the various elements of human behavioral systems are inextricably functionally interrelated. One would not expect to find a technological assemblage appropriate to a densely concentrated sedentary agricultural society being employed by dispersed small mobile groups subsisting mainly upon hunting and gathering. The technology of the latter group would be expected to be appropriate to their particular level of complexity and their adaptive strategy. In other words, their technology would be functionally interrelated and in keeping with other elements of their adaptive system.

With this perspective as a framework, cultural manifestations on the Santa Fe Forest provide an opportunity for research focused upon the question of functional interrelatedness of social systems and the development, persistence, and collapse of such systems. It is assumed here that the nature of the interface between a human social group and the physical environment is conditioned by or is a function of the level of technological, sociopolitical, and organizational complexity characteristic of the group. Such research can be approached through the comparative method, an approach which was developed and extensively employed in the early days of anthropology as a newly emerging area of social science inquiry. The geographical focus of such research would be the Jemez Mountains, which can be regarded for purposes of analysis as relatively homogeneous with regard to physical environment. Within this setting, social systems of differing levels of complexity developed, persisted for a certain amount of time and then gave way to later social systems. Research in the area should compare these social systems to one another in an attempt to understand why differing systems developed as they did, through what processes they were able to persist, and what conditions or circumstances led to their eventual replacement by later systems. The focus would be upon culture process and structural/functional variability in different systems.

The high elevation, forested uplands of the Jemez Mountains provided some portion of the subsistence base as well as some economically important resource materials for late Archaic populations. It is assumed, although not yet demonstrated, that high elevation areas (over 7000 feet) did not provide for the entire subsistence base of these populations. Such groups are thought to have been relatively mobile, and high elevation areas were probably exploited as one part of a seasonal round that included utilization of lower elevation riverine settings. We actually know very little about Archaic Period occupation and utilization of the Jemez Mountains, and many basic data remain to be gathered. It is essential that more inventory be carried out to determine the distribution of Archaic sites and that initial research be focused upon dating of Archaic sites. (See below for a discussion of the potential for dating sites in the Jemez Mountains.) The framework for data gathering should be structured with subsistence, demography, settlement, labor requirements, economy, and environment as principal elements.

As mentioned above, it is felt that sites representative of Basketmaker and early Pueblo times are present in the Jemez Mountains, although extant archeological literature suggests otherwise. Although there is limited evidence that the archeological literature is incorrect, there is a need for additional inventory. Data gathered through inventory should focus upon relevant research topics. An ability to assign sites to specific time periods during inventory would be essential.

Archaic utilization of the Jemez Mountains contrasts rather markedly with use of the same general area by Puebloan peoples several thousand years later. One element of research on the Santa Fe Forest should be a comparison of these later developments with those of the Archaic Period. The majority of research should focus upon a comparison between the Gallina culture which developed in the northern portion of the Jemez Mountains during the A.D. 1000 to 1250 period on the one hand, and subsequent though partially

overlapping developments in the Pajarito Plateau and Jemez River areas on the other. These contrasting, almost contemporaneous social systems occupying environmentally comparable niches afford an excellent opportunity for comparative research involving the relationships among subsistence, demography, settlement, labor requirements, and economy in social systems at differing levels of complexity.

As noted above, the areas around the Jemez River and the Pajarito Plateau are characterized by numerous moderate- to large-sized pueblo sites surrounded by thousands of small (one and two room) limited activity sites, many of which are assumed to be field houses. These site complexes date in the period from the A.D. 1200s up to the mid-1500s. There is also demonstrable continuity with Puebloan peoples living in the same general area today. By contrast with Archaic populations, these late Puebloan peoples were concentrated into relatively restricted areas, and maintained a fully sedentary way of life based on a predominantly agricultural subsistence base. The sites in the Jemez River area represent one of the highest-altitude, primarily agricultural adaptations known in prehistoric North America. One of the largest pueblos here is located at 8000 feet. Field houses have been recorded at elevations up to 8400 feet.

A number of the research questions identified by Upham could be fruitfully investigated with data contained in these sites. We need to determine how important agriculture was in the overall subsistence system. To what extent did they rely upon agriculture? What was the range of cultigens? It would also be an ideal situation in which to conduct research regarding the environmental tolerance of various cultigens. What level of labor investment was needed in construction and maintenance of the large pueblos found here, as well as the thousands of field houses? What level of labor investment was necessary for pursuit of an agricultural lifeway in general? The remarkable quantity of field houses is itself an ideal topic for research. Other predominantly agricultural Southwestern societies did not adopt the field house on such an extensive basis. Is there some inherent element in this high elevation setting that promoted or necessitated this particular approach to agricultural practices? How important was exchange in maintaining their social system, and what goods and services figured into their exchange networks?

In the 1000s to 1200s, the Gallina Culture flourished in the northern Jemez Mountains, perhaps in part contemporaneously with occupations in the southern part of the mountain range. This prehistoric culture is characterized by numerous scattered, relatively small hamlets, with individual sites being comprised of various combinations of pithouses, small surface structures, and the poorly understood Gallina "tower." The Gallina are also thought to have been agriculturalists, but the relative importance and extent of reliance on agriculture are not presently known. For research purposes the Gallina should be contrasted with Jemez-area Puebloan developments in terms of the relative importance of agriculture in their overall subsistence systems, the range of cultigens grown, the environmental tolerance of their cultigens, and the technology adopted to facilitate their pursuit of agricultural practices. These various elements should be considered in the light of the markedly different organizational postures of the two systems. These were nearly contemporaneous groups who occupied areas sufficiently close and comparable in elevation to be considered environmentally equivalent. They were quite dissimilar in population size and density. This contrast presents an ideal research opportunity to investigate the postulated relationship between population size and density on the one hand, and the degrees of sociopolitical complexity, subsistence intensification, and social stratification on the other. The labor investment necessary to maintain the Gallina system appears to have been substantially less than that of the Jemez River system. We know almost nothing of exchange relationships among the Gallina or between the Gallina and other groups.

Further opportunities for prehistoric research on the Santa Fe National Forest are presented by the potential for dating archeological sites with relatively little effort or monetary investment. Being in a forested area, prehistoric peoples throughout the Jemez Mountains made considerable use of wooden beams in construction. Wooden beams are currently visibly exposed in a number of large pueblos as well as in some field house structures. A program is currently under way to collect dendrochronological samples from these exposed beams and have them dated. No doubt large numbers of additional sites contain wooden beams that are datable through dendrochronology. Establishment of a well-dated developmental sequence in the Jemez Mountains area is a very real possibility. Establishment of such a sequence is considered an essential first step before one could effectively pursue the research discussed above.

Besides the potential for dating through dendrochronology, the Jemez Mountains are the location of two major Southwestern obsidian exposures, the Jemez Mountains source and the Polvadera Peak source. Obsidian is found on sites throughout the Jemez Mountains and is known to have been widely traded in northern New Mexico during prehistoric times. Although there are various problems and pitfalls with the technique, obsidian artifacts and debitage can be dated through obsidian hydration layer measurements at relatively small costs. In the Jemez Mountains such dating could initially be carried out in conjunction with dendrochronological dating for the Puebloan period. This linkage between the two techniques of dating should lead to better definition and eventual resolution of problems inherent in the hydration dating technique. If the reliability of obsidian hydration dating could

be raised to an acceptable level, we would have an excellent means of dating Archaic sites in the Jemez Mountains and elsewhere. This would vastly increase our knowledge and understanding of Archaic period developments, and make it possible to compare these developments with those of later time periods in a more meaningful way. An ability to date sites through low-cost obsidian hydration studies would open up many avenues of future research.

RECOMMENDATIONS FOR IMPLEMENTATION

The increased emphasis on cultural resources research in the Forest Service requires a revised structure to plan and manage for the future use of the Forest's data base. Cultural resources research can no longer be managed on a Forest-by-Forest basis, relying on the already overburdened Forest Archeologist to develop, plan, and implement the kinds of detailed research envisioned in this document. Instead, the existing Forest Service Research Stations should assume responsibility for cultural resources research activities.

Of course, management problems are not resolved by establishing the home of cultural resources research in the research stations. Chronic under-funding of Recreation vis-a-vis other budget line items would create a difficult situation for research station managers, if they assumed full responsibility for cultural resources research at that level. Consequently, additional funding and additional staff are needed to implement the plans for cultural resources research in an effective manner.

Presently, the Rocky Mountain Research Station receives about $140,000 annually for Recreation research. This amount would be insufficient if it was all allocated for cultural resources alone. A beginning point to implement the broad-based program of prehistoric research would be to raise the level of funding for cultural resources research to $720,000 per annum over a five-year period. Perhaps the lion's share of this amount, maybe $500,000, could be allocated directly to the cultural resources research program. This figure would represent the same proportion of FY 1988 dollars presently allocated to Recreation in the Rocky Mountain Research Station, if the total annual budget for Recreation were raised to $12,000,000. The present Recreation budget totals $2,400,000. These new dollars would be allocated according to a prioritized research plan established by the Directors and Assistant Directors of the Research Stations. Such a plan would be informed by the input of professionals outside the Forest Service, and by Forest Service personnel directly involved with cultural resources management.

Prioritized Research Objectives

The difficulty of prioritizing research cannot be over-estimated. Research deemed as critical by one group of scientists may be viewed as outmoded or (worse) doctrinaire by others. As the Forest Service research program is initiated, it is imperative that basic research be identified that is, in a sense, research-neutral. By research-neutral we mean research that does not align itself with any single interpretive position, or foster the appearance of research that has been canalized by narrow theoretical or methodological views. Consequently, the prioritized research objective identified below, and the budget and staff recommendations contained in our previous discussions, are fundamental to all research and management problems.

Chronology

Without question the current top priority for prehistoric research in the Southwestern Region is directly related to the issues of chronometric dating techniques and site dating. As revealed in our previous discussions of this issue, no single research topic is as fundamental to all basic archeological research as is work related to dating and chronology construction. At the present time, many different research questions related to the development and collapse of social systems (see Upham, this volume) cannot be addressed because of inadequate precision in existing chronologies. Other research issues too are impeded by chronological problems (e.g. duration of artifact types, site occupation spans, etc.). Finally, some aspects of the chronometric techniques themselves are poorly understood, and research needs to be completed to answer important technical questions.

Our recommendation to the Forest Service is to use the discussions contained in the section on chonology in this paper to identify research questions for study during the next five years. We believe the total funding effort for prehistoric research should be devoted to the subjects we have described.

The Role of Contract Research In the Extramural Research Program

Many of the research issues identified in this chapter and in that by Upham require scientists and investigators to make research commitments over the long term. Archeological problems often require years of careful field and laboratory work to resolve, and increasingly that research is relying on sophisticated technical instrumentation and high technology applications. One result of this new condition of archeological research is that agencies and institutions are forced to make investments in expensive equipment, thereby increasing overhead and decreasing flexibility to respond to a more broadly based set of research issues. From an institutional standpoint, the systemic result has been toward increasing specialization and the formation of laboratories and research teams with narrowly

defined goals. Within the framework of the Forest Service research stations, this alternative is undesirable.

Consequently, it is advisable from both a policy and procedural standpoint to contract cultural resources research, especially that involving high technology applications, whenever possible. The extramural research program should begin by compiling information on the qualifications of various laboratories and research teams that might be used in the future. Awards should be made on a competitive basis either as responses to RFPs or, in selected cases, as IFBs. Under no circumstances should the policy of low bid apply in the evaluation of proposals.

Monitoring of contract-related research is critical for maintaining quality in the overall Forest Service research effort. Specific Forest Service personnel should be designated as points-of-contact for each contract project. Ideally, the Forest Service contact should have some expertise in the contract area. If such personnel cannot be obtained, then an outside consultant should be retained to monitor the progress and quality of work being performed.

Partnerships and Cooperation

We believe that the Forest Service should establish a region-wide program whereby key academic institutions and scientific facilities are identified to assisted in the planning, implementation, and review of the research program. Specialists from many different fields can be contacted for guidance on key research issues. Academic institutions and scientific facilities that possess key technical equipment should be contacted, and a program of cooperation and cost-sharing should be explored. In return, the Forest Service could facilitate the conduct of research on the National Forests by key investigators at these institutions. Of course, the kind of cooperative program envisioned here would facilitate the sharing and dissemination of cultural resources research.

Peer Review

It is expected that peer review of long-term research plans would occur prior to the initiation of the research program. Management review of the program would also occur within the framework of budgeting on an annual basis. It is also expected that peer review of proposals submitted in response to contract offerings would take place (perhaps using the model of the TPEC, or Technical Proposal Evaluation Committee). These three uses of peer review are common in most, if not all, research programs. We encourage, however, an additional element of peer review in the Forest Service research program. This review process would occur on a biannual basis by outside personnel (academicians or non-academic specialists), and would be directed at assessing the overall research effort. Such review would include, minimally, evaluation of long- and short-term research objectives, analysis of past, current, and pending research in light of these objectives, and recommendation of revisions or additions to the existing plan.

The last element of the fourfold model of peer review described above will ensure continued credibility of the Forest Service research program with the professional community, and will discourage perceptions that the Forest Service has established a closed research shop or is too closely linked with a given group of researchers or ideas. Maintaining this standard of credibility will permit greater flexibility in research over the long-term, and will serve as a vehicle for comprehensive evaluation of the research program and its objectives both within and outside of the Forest Service management framework.

CONCLUDING THOUGHTS

Archeology, like science in general, has as its primary goal and raison d'etre the advancement of knowledge, in this case the knowledge of past and present human behavior. Research as a management tool represents an important, but nonetheless secondary, function of science. Superficially, the subject of key prehistoric research seems only tangential to the management aspects of archeology, and to relate almost exclusively to the first aspect. However, the management of "cultural resources" can be approached from the perspective of the first aspect if archeological remains are viewed as scientific resources, that is, as sources of information useful in furthering knowledge.

The "scientific resource" perspective localizes criteria for archeological resources mangement in the scientific value of the resources rather than in their "cultural" value. The scientific value of such resources is not immutable, but changes as science itself develops. Thus, management criteria can be expected to evolve along with the science of archeology. This approach to resource allocation may at first glance seem antithetical to the management approach. This need not be the case, however. The approach advocated here is directly analogous to that used in accumulating data for the wise management of natural resources. Just as the proper management of mule deer or spotted owls rests on knowledge of the behavior of these animals, so the most effective management of cultural resources depends on knowledge of the behavior of the humans who produced the sites. Despite this conceptual identity, the focus of the research differs between the natural and archeological domains. While the behavior of deer and owls can be directly observed, the behavior of prehistoric humans can be only indirectly observed through the material remains of their activities. Nevertheless, the fact remains that, however indirectly achieved, knowledge of past human

behavior is vital to understanding and managing Southwestern cultural resources. For example, knowledge of the land-use practices of a past population can be more useful for the management of cultural resources than objective data on sites in the target area.

Misconceptions about the nature of cultural resources and of archeology hamper the implementation of effective management programs based on either the scientific or management aspects of archeological research. Archeology comprises at least two major components, description (prehistory) and explanation. The "library" analogy advanced at this conference (Muniz, this volume) is not totally inappropriate for conceptualizing the descriptive mode of archeological research. It is remotely conceivable that a point can be reached where everything that can be learned archeologically about the prehistoric human events of an area has been learned. Attainment of such a position would complete the ultimate volume of the library on the prehistory of that area.

The "library" model, however, is not compatible with the explanatory mode of scientific research. No matter how much is known about the prehistory (description) of an area, archeologists will never cease trying to explain the behavior that produced the prehistory. New theories of human behavior and of the relationship of that behavior to material remains, new research questions generated by theoretical developments, and new technical methods will engage archeologists in a perpetual round of examination and reexamination of their data. Consequently, there will always be a need for an intact archeological data base.

Consideration of the "scientific resource" approach to management and of the dual nature of archeological research lead inescapably to the conclusion that all archeological sites are significant relative to current or future research orientations. Therefore, the preferred cultural resources management strategy is the complete protection of all sites for all time at all costs. Obviously, though, such approach to management would be totally impractical, and is not advocated here. Clearly, some compromise must be reached between the needs of archeological research, for either management or knowledge,and effective management of Forest resources in general.

Fortunately, a compromise that eliminates the need to make all-or-nothing decisions about allocation of cultural resources is possible. This allocation strategy responds to both the descriptive and explanatory modes of archeological research and to management realities. It is based on the scientific view that sites are and always will be sources of scientifically-useful information. The proposed strategy promotes the conservation of archeological information and involves the distinction between protection (keeping sites from harm) and preservation (keeping sites from change). Scientifically, there is no justification to preserve all sites from the natural entropic processes of degradation. This type of site transformation is part of the archeological domain. Furthermore, attempts to preserve sites often obliterate or render inaccessible the scientific information they contain. Thus, preservation should be infrequently employed and then primarily for educational (display) rather than scientific purposes. In contrast, the protection of sites from inadvertent or purposeful damage by humans is a legitimate concern. Passive protection involves avoiding sites whenever possible so as to preserve their archeological integrity. Active protection involves efforts to control and eliminate pothunting, vandalism, and other intentional assaults on the archeological record. In cases in which impacts can be neither avoided nor circumvented, a procedure of preservation through study should be invoked. This means that all possible information should be extracted from imperiled sites before they are disturbed or destroyed. Detailed documentation, surface collection, or excavation can preserve valuable information on the sites in the form of materials and data. Encouraging extramural research on endangered sites would be a cost-effective means of accumulating such information.

The allocation strategy outlined above is based on the precept that knowledge of the resource is the key to wise management. Two kinds of knowledge are involved. Empirical information on the archeological record based on inventories and analyses of survey data constitute one kind of knowledge. The other involves understanding the human behavior that produced the cultural resources, and is directly analogous to the use of knowledge of animal behavior to manage faunal resources. In this strategy significance is determined as much by knowledge of past human behavior as by the empirical characteristics of the archeological record. This represents a "proactive" rather than reactive approach to the allocation of cultural resources.

To conclude, the proposed cultural resources allocation strategy focuses on the protection rather than the preservation of sites. Protection can be achieved through the avoidance of sites whenever possible, coupled with an active vandalism-suppression program. When avoidance is impossible, or when natural processes threaten destruction of important data (perishable items, for example), a policy of preservation through documentation should be followed. Endangered sites should be recorded in detail, associated materials should be collected and stored, and, in cases of imminent destruction, the sites should be excavated. This approach would preserve valuable information that could be used by future generations of archeologists. In this way, at least some aspects of sites permanently removed from the cultural resources research base would not be lost but would be conserved for posterity.

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The Spanish Colonial Research Center Quincentenary Project: a National and International Model for Cultural Resources Management and Interpretation Research[1]

Joseph P. Sanchez[2]

The Spanish Colonial Research Center is a joint project between the National Park Service (NPS) and the University of New Mexico. The Center was established to assist the National Park Service in its preparation for the Columbus Quincentennial in 1992. The Center's mission, to collect and analyze Spanish Colonial documents, will result in long-lasting benefits to the National Park Service. Much of the data base will be used to upgrade exhibits, publications, and audio-visual scripts at NPS sites, as well as for training of NPS personnel. In addition to the development of the documentary data base, the Center has cooperated with the Spanish Ministry of Culture in Madrid on a two-year research project, and has exchanged ideas with the Spanish National Commission on the Quincentenary (Madrid) and the Committee for "Expo 92" (World's Fair) in Sevilla. In June 1988 the Center, working with the University of New Mexico and the Fundacion Xavier de Salas (Trujillo), will co-sponsor a symposium entitled "Primer Encuentro entre Extremadura y Nuevo Mexico" at Trujillo. The symposium is funded by the Comite Conjunto Hispano-Norteamericano in Madrid.

The Center was established as a Service-wide research program in 1986 on the University of New Mexico campus, Albuquerque, New Mexico. Organizationally the Center receives its direction from the National Park Service Columbus Quincentennial Task Force administered by the Associate Director, Cultural Resources, Washington, D.C. Administratively, the Center coordinates NPS Quincentennial Research Requirements through the Regional Director, Southwest Region, Santa Fe, New Mexico. As the only unit of the National Park Service that exclusively addresses the research needs of Spanish Colonial Heritage sites and related matters, the Center works closely and cooperates with the Office of the Vice President for Community and International Programs at the University. A Memorandum of Understanding, signed in the summer of 1987, enables the Center to coordinate its research activities with UNM faculty and students. In association with the University, the Center provides additional opportunities for national and international scholarly exchanges.

Materials in the Center's collection date from the Age of Discovery. The collection includes documents useful for research regarding Columbus' second voyage, and his discovery of the Virgin Islands or Puerto Rico. Furthermore, the documentation covers a chronological period from 1492 through the early 1800s. The distinctive writing styles of Spanish Colonials and historical situations within these various time frames present a challenge for researchers of Spanish Colonial California, Arizona, New Mexico, Texas, Louisiana, and Florida.

Documents in the Center's collection are representative of Spain's 328-year administration of the empire's northern frontiers. They are primarily from the archives in Sevilla, Simancas, and Madrid, Spain, and Mexico City. These depositories contain millions of Spanish Colonial documents. For instance, the archive in Sevilla houses approximately 40 million pages of documents, and another 30 million pages are housed at the archive in Simancas. The oldest archive at Simancas contains documents related to the early history of the Americas. The Archivo General de Simancas was founded soon after Columbus' third expedition. The archive is comprised of the various files from secretaries or counsels who advised the king on the empire's administration. For the sake of improved record keeping, it was decided to house all documents in one place.

Mexico City's national archive is estimated to house several million pages of documents. This does not take into account documents in various provincial archives, such as those in Sonora, Chihuahua, or Coahuila. Large numbers of documents also exist in the other states and in private collectors' archives throughout Mexico. The documents contain records of the Spanish Colonial administration of natural resources. These documents reveal that Spanish explorers recorded in their maps, plans, sketches, diaries, and correspondence information regarding land, climate, resources, and people. Colonialism is given a new meaning in light of these revealing records.

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[1] Paper presented at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2- 6, 1988).

[2] Joseph P. Sanchez is Director of the National Park Service Spanish Colonial Research Center, University of New Mexico, Albuquerque, N.M.

In order to assess the significance of Spanish Colonial Heritage sites, the Center stresses a comparative colonialism as a perspective. Colonialism in the United States is usually defined from the English point of view. It is assumed that English Colonialism spawned democracy; however, democracy is the antithesis of colonialism. English Colonialism must be viewed in its proper perspective. This can be accomplished by examining the history of British expansion from the Caribbean to India. Likewise, modern-day French Colonialism in Algeria offers the history student one of the most tragic examples of colonialism. Today the vestigial colonialism of the South African situation is analogous. Present-day Western Civilization is still overshadowed by colonialism in more ways than is realized. Our world is perceived in terms of a colonial and neocolonial approach. Spanish Colonialism is misconstrued in many ways, primarily because of the cruelty of conquest associated solely with the Iberian expansion. Yet French, English, German, and Portuguese Colonialism did not much differ from Spanish Colonialism. However, existing documents on Spanish administration in the Americas inspire a completely different impression.

Maps, plans, sketches, and other documentation in Spanish Colonial archives are an asset for exploring the past. Aside from physical and topographical land features, documents reveal locations of many natural resources, as well as the locations of native populations. Colonials exploiting raw resources found this knowledge invaluable in meeting their needs for a cheap labor force. As a result, a colonial-native relationship was formed wherever Spaniards settled. Valuable insight is gained from these documents on colonial-native relationships and the exploitation of raw resources.

Spanish Colonial maps reveal where rivers, mountains, pasturage, salt-deposit zones, and minerals are located. Rather than communicating place names and the shortest route from point A to point B, Spanish Colonials seemed preoccupied with conveying relevant information related to natural resources, and with locating low-cost native labor forces.

The knowledge acquired from the cartographical collection at the Center reveals the extent of Spanish Colonial interests in North America. For example, an 1819 map depicting all lands north of Santa Fe - northern New Mexico and Colorado - indicates the range of the Spanish Colonial sphere of activity in the northern edge of the empire. A particularly interesting physical feature included on the 1819 map is the Yellowstone River. Also, attached to the map are a series of documents describing the Yellowstone country, and a 1819 plan proposed by Facundo Melgares of Santa Fe to lead an expedition to the Yellowstone country as soon as the "weather warmed a bit."

Similar documents are available for many areas of North America. Georgia and Florida are just two examples. Other examples include the Caribbean, the lower South, the Southwest to California, and the far north to Alaska. All of these areas were considered part of the Spanish domain.

The Spanish Colonial archives also contain documents related to the American Revolution. Documentation includes interviews by Spanish officers with American officers in order to determine the status of the American cause. Letters reveal interviews with George Washington in his tent headquarters, as well as those held with British commanders at their headquarters.

Spaniards also mapped many strategic areas during the American Revolution. These include maps of various Revolutionary War battle sites. Some examples of mapped areas are Philadelphia, Charleston, and Boston. Therefore, it seems reasonable that National Park Service American Revolutionary sites could unite with Columbus Quincentennial efforts in a way that would permit a unique type of interpretation. After all, the French are interpreted at English Colonial sites, so why not examine the Spanish efforts along those lines? Besides these records of Spanish Colonial ventures in North America, there are also maps, plans, and sketches on the American Westward Movement that the Jefferson National Expansion Memorial would find very interesting. Indeed, plans of the fortification of St.Louis, Arkansas Post, and New Orleans offer a view to the past which can assist archeologists as well as historians in their Quincentenary research projects.

The Spanish Colonial Research Center with its growing collection of 20,000 pages of microfilmed documents, transcriptions, and translations is project-oriented. Its site-specific research is aimed at preparing the National Park Service for the Quincentenary in 1992.

Archeology of the Ephemeral: Research Themes for Western Historic Sites[1]

George A. Teague[2]

Abstract.--Historical archeology is defined, and its trends and traditions are described. Dominant research themes are extracted. Applications for these themes are suggested within the context of Forest Service land management.

In this paper I will summarize the state of research in historical archeology, provide a list of current research themes, and touch upon ways historical archeology might apply to Forest Service properties in the Southwest.

The primary problem in dealing acheologically with historic period sites is what I call the "Oh Yeah" syndrome. Even when line managers have become sensitive to their legal responsibilities to archeological sites, it takes some prodding to get them to say, "Oh yeah. There're also some old adobes and mines out there. You don't care about those things, do you?" They can't really be blamed for this. A variant of this attitude emerges even among the archeological fraternity. I can remember, to my shame, running surveys as recently as the early 1970s and giving historical sites exceedingly short shrift in my eagerness to get to the "real" archeology. Even today, a typical survey report pays loving and seemingly interminable homage to prehistoric cracked rocks, then finishes off with an "Oh Yeah" appendix on historical sites. Historical archeology is still something of a stepchild. Nonetheless, with the burgeoning of the Cultural Resource Management (CRM) movement in the mid-1970s, the framers of law and policy wisely included historical sites along with prehistoric sites. We have, then, the obligation to give tin-can archeology the same level of treatment that we give to prehistoric ruins. The question, of course, is what to do with piles of broken glass, old wall footings, and mine shafts.

To put this in perspective, I'm going to give a brief history of historical archeology, and extract some of the trends and themes that have informed it. But first some definitions and scene-setting. The term "historical archeology" has been around in more or less its present form since the 1930s (see Woodward 1937), but has meant many things to different people. The early emphasis on historically significant sites (like Jamestown) led to use of the term "historic sites archeology" (Harrington 1952:336). But eventually, the term was felt to be overly restrictive, and the rubic "historical archeology" was adopted after heated debate (Anonymous 1967). The squabble over terms may seem academic in retrospect, but led to the important distinction that all sites of the historic period were worthy of attention, not just the Jamestowns and St. Augustines. An early definition by Fontana has it that the archeology of historic sites is:

> archeology carried out in sites which contain material evidence on non-Indian culture or concerning which there is contemporary non-Indian documentary record (Fontana 1965:61).

Fontana was referring to sites of the New World, and his concern was strong regarding the relationship of newcomers to the native inhabitants. Other definitions have followed, but Fontana's remains the best, being specific enough to cover the kinds of sites that have been investigated.

The beginning of the period of interest coincides with the arrival of the first Europeans. The end of the period is more problematic. It would seem reasonable to put no limitation on the upper end of the sequence. It is easy to forget that the archeology of the Late Victorian Period was a novelty in the 1960s (see Fontana and Greenleaf 1962; Brose 1967), and the archeology of the 20th century was unheard of

[1]Paper presented at the symposium, "Tools to Manage the Past: Research Priorities for Cultural Resources Management in the Southwest." (Grand Canyon, Arizona, May 2-6, 1988.)

[2]George A. Teague is an archeologist at the Western Archeological and Conservation Center, National Park Service, Tucson, Ariz.

until the 1970s (see Adams 1977; Brown 1978). Both are now commonplace. Furthermore, methodological issues, enthoarcheology, and studies of modern material culture have been pursued using very recent sites. In common practice, however, there is an unspoken consensus that about AD 1930 marks the end of the period of interest in mainstream historical archeology. This may be because of the rule of thumb that normally excludes sites less than 50 years old from consideration for nomination to the National Register of Historic Places unless there are special conditions of significance. In fact, it is a piece of CRM folklore that managers love to bulldoze 49-year-old buildings to avoid the agony of having to deal with the miserable things. I'm sure these tales are apocryphal.

Now I'd like to ask what kinds of sites historical archeologists investigate and, needless to say, I'm going to answer my own question. I conducted my own personal straw poll by looking at about 150 substantive journal articles and monographs published in the last 20 years, and seriating the site types and site ages by date of publication. What I came up with was that historical period Indian, fur trade, and colonial sites are now less frequently excavated than before. Mexican period sites are now more frequently investigated. Interest in American military sites continues unabated. Attention to homesteads, urban domestic, antebellum Black, and industrial sites has been on the increase during the last 10 years, and reporting on these site types now dominates the literature in absolute, as well as relative, terms.

As for the central period of interest, earlier sites, that is those of the colonial period, were excavated in disproportionate numbers prior to 1970, and continue to be reported on to some degree, perhaps out of sheer rarity value. Likewise, the years 1850-1875 encompass the American Civil War and the frontier Indian campaigns, and interest in sites of this period remains high. The real surprise is that excavation of sites of the late Victorian period and the early 20th century has increased considerably, while excavation of earlier sites has decreased in frequency. This may be due in part to ascendancy of the "new social history" which places value on the history of the ordinary man. Also, sites that would have been ignored in years past must now be assessed and treated equally in the course of CRM projects.

Now to get down to specifics about the Forest Service holdings. On the New Mexico properties, at a rough estimate, as much as a fifth of the historic period sites may date from earlier times: that is, protohistoric and historic Indian occupations, or Spanish Colonial and Mexican Period occupations. In Arizona, the number of early historic sites is likely to be even less. The remaining sites will date to the so-called "American Period," lasting from the 1840s to the present. I would venture to guess that the great majority of historic sites in southwestern Forests will date to the late 19th and early 20th centuries, coincident with the coming of the railroad, homesteading, and the quickening of American industry and its needs for ore and timber. This puts things in a new perspective. Rather than the intrinsically interesting and far-removed colonial sites, what we will most often encounter are the remains of ranches, mines, and homesteads. We will most often be doing the archeology of the recent and commonplace, not the old and exotic. And most of the sites will have been ephemerally occupied. Our scope of interest must perforce be directed to failed towns, played out mines, abandoned logging camps, and hapless homesteads. To understand what to do with these I'm going to summarize the five major traditions in historical archeology, and extract the themes that characterize each.

While there were some early stirrings of interest in digging up historic sites (see Schuyler 1975; Deagan 1982), the real start of the discipline can be traced to the 1930s, and this start can be linked to the legacy of historicism. Massive federal work-relief programs of the 1930s proved an unexpected boon for the monuments and heritage interests. The era began inauspiciously with enthusiastic but erroneous reconstructions at a number of sites. The purpose of the restorationists was primarily to provide more by way on interpretation for visitors as well as to stabilize crumbling architecture. As a consequence, sometimes-bewildered archeologists, trained as prehistorians, found themselves digging for historic architectural and locational information. In some lamentable instances, digs were conducted primarily to fill museum cases.

There were, however, landmark studies that transcended the limits of pure historicism. These included excavations at Jamestown, Awatovi, and La Purisima Mission in California (see Cotter 1958; Montgomery and others 1949; Schuyler 1975:64ff). These studies were marked by the discovery of new excavation methods and artifact chronologies. The monuments orientation was continued through the years at such places as Fort Raleigh, Williamsburg, and Brunswick Town (see Harrington 1952, 1966; South 1964), with further refinement in research techniques and artifact analysis. Perhaps the most noteworthy achievement was that anthropologically trained archeologists began to treat historic properties as conceptual analogs to prehistoric sites, in terms of analytical strategies.

By the 1950s, archeologists were chafing under the restraints of the monuments and heritage movement, and had assumed the larger role of "filling in the gaps" in the historical record. They were aided in the endeavor by a new influx of money earmarked for the River Basin Survey project, which was spent on the salvage excavation of a number of forts and trading posts in the Midwest (Mattes 1960). The major advance of this period was the recognition of low-visibility sites, although history and archival research still served to drive the studies.

The salvage movement persisted through the 1960s and early 1970s, when it was transformed into CRM. Extensive description still characterizes the reporting on salvaged sites, but advances in methodological sophistication are regularly grafted on. In fact, it is now impossible to distinguish a good salvage report from one prepared for other reasons.

As new concepts in historical archaeology presented themselves, so were needed new typological and methodological constructs. A number of ways were found for the pragmatic application of low and mid-order quantitative techniques such as linear regression, seriation and cumulative graphing. Manipulation of artifact attribute frequencies has become the hallmark of modern historical archeology; if there is one thing everyone knows about historical archeology, it is that clay pipestem diameters give dates through seriation. Historical archaeology is in fact probably academia's leading consumer of the battleship-shaped curve.

In addition, over the years artifact analysis was wrested from the hands of antiquarians and art historians. Taxonomies on all aspects of historic period material culture have been developed empirically from recovered materials, and chronologies have been developed on the basis of stratigraphic relationships. Thus, cross-regional comparisons may now be made. Analysis has been marked by increasing use of statistical techniques, and other techniques from prehistory, such as faunal and pollen analysis.

Historical archeologists have also gone beyond the bounds of history and into the realm of anthropology. As early as 1951, Gordon Vivian asked questions about past social processes (Vivian 1964). He wanted to know why Gran Quivira was destroyed while other similar pueblos survived and prospered. His findings led him to believe that culture contact and subsequent population mixing resulted in a lack of group social integration. Consequent internal dissension left the group ill-equipped to deal with environmental deterioration and pressure from nomadic populations.

There were soon to follow other examples of social reconstruction, particularly in the areas of assimilation, ethnicity, status, and settlement. The seminal study in this regard was Deetz's (1963) investigation of the Mission La Purisima at Lompoc, California. Deetz assumed the dominant mechanism of acculturation to be missionization. The proposition was tested by examining differential loss of native material culture. Deetz hypothesized that, as a result of missionization, there would be a loss of male-related items of indigenous technology, such as chipped stone tools, and the retention of female-related items like milling stones and comales. There would also be replacement of many other items in the aboriginal repertoire with items of European technology.

In distinction to Deetz, Deagan (1973) rejected the importance of the mission system as an agent of acculturation among the Florida Indians. She argued that it was the mechanism of mestizaje, the marriage or concubinage of Indian women with Spanish soldiers, that provided the "most viable channel of exchange of cultural elements" (Deagan 1973:57).

Other arguments to explain culture change, but taking economics and trade as prime movers, were Irwin-Mason's (1963) study of the Creek, and Deetz's (1965) well-known study of Arikara sites.

Archeological studies of ethnicity have centered on the discovery of artifact patterns, activity sets, or assemblages that allow differing historic ethnic groups to be recognized in the archeological record (see Schuyler 1980). In the East, a number of studies have focused on discovery of Afro-American patterns (for example, Otto 1984; Baker 1978; Deetz 1977a). Sites once occupied by slaves or Free Blacks are distinguished from Euro-American context by evidence of differing access to goods, food, and housing; less participation in national market systems; the presence of differing units of measure (12 foot rather than 16 foot spacings); and differing serving and eating assemblages. Similar studies are being conducted at Chinese sites on the West Coast (for example, Teague and Shenk 1977; LaLande 1982).

Studies of status spring naturally from consideration of ethnicity. Joan Geismar (1982) linked the social disintegration of a Black community to the decrease in status of certain high-ranked individuals. She traced this change in status by examining the relative value of pottery found in deposits of differing age and association. Fortunately, in historical archeology you can sometimes learn how much a set of dishes cost at the time they were bought (see Miller 1980). Similar status-linked studies have been done by analyzing bone and determining the relative costs of meat consumed by differing households (for example, Mudar 1978). In other words, were people eating steak or hambone soup?

Interest in patterns of settlement as they relate to the landscape has always been present to some degree in historical archeology. It is a rare report that doesn't deal with settlement patterns at least at the site level. However, beginning in the 1980s, historical archeologists have been borrowing locational models from the prehistorians, who in turn have often borrowed them from cultural geographers, social historians, and economists (for example, Paynter 1982, Lewis 1976). Thus we now see the whole array of Thiessen polygons, nearest neighbors, and world systems imposed on unsuspecting historic sites. Models have also been borrowed from cultural ecology, with varying degrees of sucess (see Hardesty 1980-81; Kornfeld 1983).

Over the last ten years there has been considerable preoccupation with the development of some sort of theory unique to historical archeology. In 1977, two remarkable books appeared, South's (1977) Method and Theory in Historical Archaeology and Deetz's (1977a) In Small Things Forgotten. By coincidence, two influential (and ultimately competing) approaches had arrived on the scene at the same time. South argues for the merits of "pattern recognition studies" of material culture, while Deetz advanced the idea of "mind set," also presumably recognizable in material culture. Both are materialistic, in the sense that both look to artifacts and architecture for clues to the past, but the approaches are clearly different conceptually, with one proceeding from the ground up and the other from the mind down, so to speak. South considers himself an evolutionist, while Deetz pays homage to structuralism of the French variety. There has been much flailing about by others in search of a theoretical hook upon which to hang these ideas.

Pattern recognition studies are an attempt to order artifacts into functionally related groups (kitchen, arms, architecture and so on). Suites of artifact groups are then set up as temporal/typical models. These models are compared in terms of frequency variation with those from other regions in order to delineate functional, temporal, or behavioral differences between sets. South has distinguished two kinds of patterns. The spatial variety has to do with distinguishing types of waste disposal within a site. The Brunswick Pattern is one of trash disposal directly at points of entrance and exit of buildings in 18th century British sites. It is thought to be a diagnostic site-type marker, in a manner of speaking. Other patterns are recognized on the basis of intra-assemblage variability. The Carolina and Frontier patterns establish norms and ranges of artifacts for various Colonial British military and domestic sites. The patterns establish a yardstick by which other sites may be measured for function and identity. The two patterns co-vary, especially in frequencies of kitchen- and arms-related artifacts.

Deetz's mind set approach was anticipated by Leone (1973) and was given initial direction by the work of Glassie (1968, 1975). Leone (1973) studied the layout of Mormon communities of the Little Colorado drainage of Arizona. He argued that building and fence layout reified and reinforced an ideology concerned with strict equality within a communal system; redemption of the earth; replication of an idealized environmental view; and demarcation of the sacred and the profane. In a later study Leone (1977) considered the cosmological aspects which dictate the construction features of Mormon sacred architecture.

Glassie (1975) studied folk housing in Virginia for evidence of changes in vernacular architecture which could be related to shifts in world view. The Glassie program applied a form of structuralist grammar (called "architectural competence"), whereby any form can be transformed by generating new forms based on the transformational rules. Glassie extracted what he considered the basic form of the British Colonial housing tradition, the 16-foot living unit. Housing was seen to grow by multiples of the basic unit in tightly structured ways. Also valued by the early American builders were bilateral symmetry, tripartite building divisions, and provisions for individual privacy. These elements were thought to reflect a new, rational order which extended to other aspects of life.

Deetz accepted Glassie's conclusions, perhaps because they coincided so well with the idea of "mental templates" which he had promulgated earlier (Deetz 1967). Deetz, in his 1977 book, looked into changes in the form and function of material culture in early New England, with special attention to floor plan, placement of windows and doors, and inventories of eating and serving utensils. He found an apparent change from communal eating and sleeping arrangements, to individual dishes and divided symmetrical floor plans in later periods. Following Glassie, the ideological component to account for these differences was considered to be a change from Medieval to Georgian mind sets (or world views) about the place of the individual in society. The later, Georgian, penchant for symmetrical order is considered to have been unconscious, but nonetheless pervasive throughout the culture.

There have been numerous criticisms of both pattern and mind set approaches. Regardless of criticisms, both pattern studies and mind set studies are with us 10 years after their introduction and, in fact, serve as rallying points for most methodological debate in the discipline today. The pattern approach is seductive; it is something we can actually do, and the heavy quantification attendant upon it is attractive to the science-minded. Mind set studies are equally seductive in their intuitive appeal. Hypotheses brought forth simply make sense, regardless of the fact that they are nonfalsifiable, and hence ultimately untestable. Handsman (1983:65) states that "no matter how much one tries, one cannot put Deetz and South together." On the contrary, the two approaches seem in many ways to be the same thing in different guises: an attempt to find the reason for order in the material world. Deagan used both approaches at St. Augustine, as did Fawcett (1983) for a variety of other sites, demonstrating to me that the approaches are not only compatible, but are operationally identical. Thus far, though, pattern recognition and mind set studies remain methods in search of theory. The parallels with the Configurationalist school, as exemplified by Benedict (1932) are, however, worth noting. As Benedict "emphasizes a culture's strain to consistency" (Harris 1968:401), so too do Deetz and South. We may be excused for imagining a rebirth of the Configurationalist approach in their work.

To sum up, there are five overlapping traditions in historical archeology. We proceed from the monuments and heritage movement to historical description, to anthropological

systematics, to social reconstruction, to pattern studies. It is interesting to see that, since World War II, historical archeology has recapitulated the 100 year history of prehistoric archeology, beginning with an obsession with museum specimens, and ending with a search for overarching theory. However, there should be no supposing that these approaches have scaled some sort of evolutionary pinnacle, nor less has a consensus been achieved. Instead, each of the major traditions persists at present to serve one or another of the various Balkanized provinces of the field.

There are several research themes that can be extracted from the traditions of historical archeology.

1. The strong survival of historicism, which involves locating and identifying monuments and historically notable sites. Also involved is the rather humble enterprise of "filling in the gaps" in the historical record.

2. Refinement of methods, techniques, taxonomies, and chronologies, especially as it involves construction of empirically derived models and using the historical record as a check.

3. Concern with reconstruction of past social systems. The dominant subthemes are studies of assimilation, status, ethnicity, settlement, and subsistence.

4. Search for a unifying theoretical synthesis, as exemplified in materialist and cognitive pattern recognition.

Having said all that, I want to introduce my own view about the directions historical archeology should take. My viewpoint is not only biased, but is out of the mainstream of thought within the discipline. It may, however, serve as a springboard for discussion. As a starting point, I want to refer to Deetz (1977b) who has argued that archeology in general may be evolving into a discipline concerned with the "science of material culture" regardless of temporal context. Furthermore, South has taken the radical position that productive historical archeology can be done in the absence of history, if necessary. He notes that material patterns discovered at historical sites "...may well have absolutely no historical counterpart; indeed mutually exclusive data sets from the historical and archeological records almost appear to be the rule rather than the exception" (South 1977:326). This is also my impression, and leads me to the following observations:

1. Historical sites are best seen as broad arrays of material culture, subject to the extraction of statistical patterns. These data can be synthesized to produce a kind of fact having a truth of its own at least equivalent in value to historical truth.

2. It follows that there is little conceptual difference between treating historic and prehistoric sites. Most of the same standards and techniques may be applied.

3. For that matter, the difference between doing prehistoric and historical archeology is insignificant. Both are forms of reconstructive history and retroactive ethnography (see Deetz 1988; Young 1988 for discussion).

Now, if you accept these tenets, you are compelled to believe that our job is not to be a handmaiden to history, nor to furnish detail to people who want only to rebuild historic forts. Rather, our job is to locate historic period sites and assess them in terms of their potential to inform us about the past. This is where the research themes come in. From a management point of view, our first task is to determine if sites on Forest Service land are useful for pursuing meaningful research questions. However, I am strongly opposed to development of a laundry list of acceptable research themes. In this there is the danger of masking real variability and ignoring social and structural complexity in the past (see Anderson 1985). And there is also the uncomfortable knowledge that dominant research themes will without doubt change in years to come.

To conclude, there are those who feel that other aspects of historical archeology are of importance as well. There are issues of site preservation and interpretation, the role of archival research, and the public's desire for tangible, physical connections to the past. I assume that others will take up these banners in this symposium. But I feel that the most pressing managment need at the moment is the need to know what we have in our public landholdings, and what it's worth, so that informed decisions can be made about site treatment.

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Toward the Creation of a Research Work Unit[1]

Joseph P. Sanchez[2], George Teague[3], James T. Rock[4], David M. Brugge[5], David Siegel[6], and Scott Wood[7]

The following model presents the Forest Service Southwestern Region and the service area of the Rocky Mountain Forest and Range Experiment Station with a feasible program for conducting historical research for the benefit of cultural resources management, general forest management, and future interpretation. The format of the plan, which calls for the creation of a Research Work Unit, includes a rationale, objectives, list of suggested topical areas for research, methodologies and techniques, and estimated staffing and funding requirements.

RATIONALE

As the nation's second largest land-managing agency, the U.S. Forest Service has a preeminent part to play in the Federal historic preservation effort. Although the inventory of our public lands under Forest Service jurisdiction is far from complete, systematic studies conducted within the last several decades have established that the National Forests embrace a prehistoric and historic resource base that may be unparalleled among the primary Federal agencies. This is particularly true in the Southwestern Region, which contains what is probably the best-preserved record of human history and prehistory in the National Forest System.

In keeping with the leadership role of the Forest Service in cultural resources management, and in furtherance of its legislative mandates to identify, preserve, and enhance prehistoric and historic values, it is proposed that a new Research Work Unit be established within the Rocky Mountain Forest and Range Experiment Station. The Research Work Unit would be composed of two principal sub-divisions, a prehistoric work unit and a historic work unit. It would function as a professional scientific, historical, and curatorial facility that would be devoted to: (1) providing professional support for management of prehistoric and historic resources; (2) consolidating and directing Forest Service research needs in the area of prehistoric and historic resources; (3) ensuring that Forest Service management of these resources is consonant with National preservation goals; (4) serving Forest Service planning needs; (5) ensuring and maximizing public interpretation of cultural values on Forest lands; (6) furthering scientific research and meeting the standards and expectations of professional communities, and (7) facilitating compliance with legal requirements, departmental policies, and directives. Models of the kinds of work that the Research Work Unit, as well as National Forests, could undertake are shown in figure 1 and tables 1 and 2.

The Research Work Unit would function as a support service to all Regional, Forest, and field divisions, and provide assistance when requested to other federal and state agencies, institutions, and private concerns. This support could be obtained through the RWU or shared services with other agencies.

OBJECTIVES

The objectives which derive from the Rationale include more specific goals to provide Forest Service management with information necessary to manage and interpret historic resources. Specific goals are:

1. Conduct substantive research that lends itself

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[1]Paper prepared at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2]Joseph P. Sanchez is the Director of the National Park Service Spanish Colonial Research Center, University of New Mexico, Albuquerque, NM.

[3]George Teague is an archeologist with the National Park Service, Western Archeological and Conservation Center, Tucson, AZ.

[4]James T. Rock is Forest Archeologist, Klamath National Forest, Yreka, CA.

[5]David M. Brugge is Chief of the Branch of Curation, Southwest Cultural Resources Center, National Park Service, Santa Fe, NM.

[6]David Siegel is the Regional Archeologist of the U.S. Fish and Wildlife Service, Albuquerque, NM.

[7]Scott Wood is Forest Archeologist, Tonto National Forest, Phoenix, AZ.

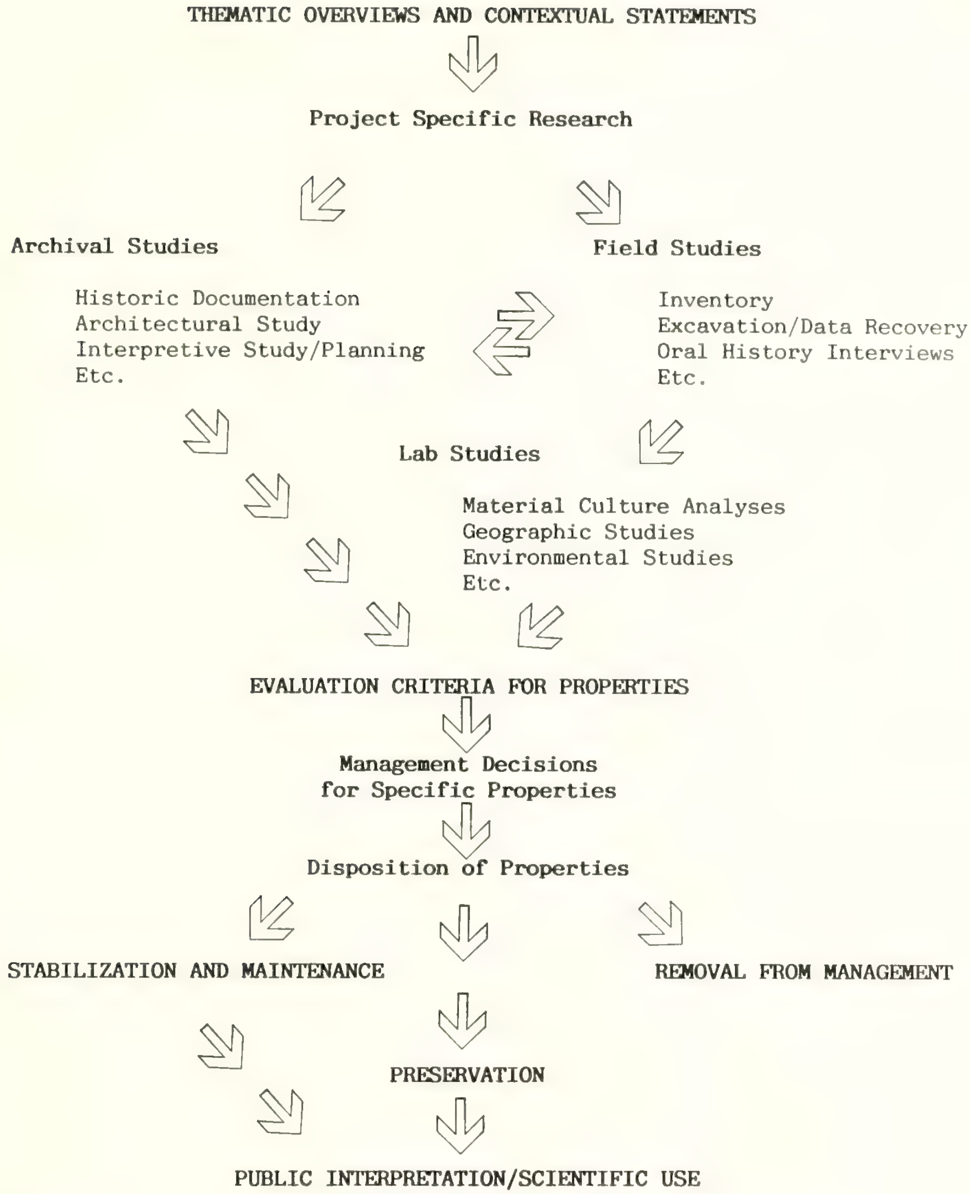

Figure 1. Research Hierarchy for Management Support Documentation

to the management of resources. This research comprises location, identification, and contextual evaluation of resources.

2. Provide a data base to the Forest Service and other agencies for use in CRM compliance procedures and accountability systems.

3. Provide a synthesis of research findings which will allow interpretation of the resources to the Service and the public.

4. Disseminate research results to the Service, the public, and the academic community.

HISTORIC RESEARCH TOPICS

It is assumed that the model for the Research Work Unit covers the Greater Southwest, and that the historical periods included for the historic sub-unit are: the Spanish Colonial Period, 1500-1821; the Mexican National Period, 1821-1848; the Anglo-American Period of Westward Expansion, 1800-1890; and the Modern Southwest, 1890 to the present. It is understood that Native American populations are of interest, and that other national and ethnic groups are included insofar as they pertain to the historical periods under investigation.

Research topics covering episodes, events and processes in Southwestern history are subsumed under the major institutions of culture: economics, religion, and sociopolitical organizations.

Three general themes are proposed to

Table 1.--Research structure and decision-making in context: example 1, research, analysis, and management of a skid shack railroad logging camp in California.

Responsibility	Activity/Product	Study Topic/Decision	Example
		Forest Economics	
Research Station	Overview	Logging	
	Overview/ Monograph	Railroad Logging	
	Topical History	Specific Area/Topic	A. Weed/Long Bell Railroad Camps, 1896-1956
Research Station		Site identified	Logging Camp: 1910
	Site Record	Site Inventory	RR grade and can scatter
or			
	Analysis	Data Collection	Artifact Collection
Forest			
	Documentation	Evaluation w/SHPO	Data recovered
Forest	Site info. retained only in database and repository	Management restrictions on site removed	

Table 2.--Research structure and decision-making in context: example 2, research, analysis, and management of Forest Service administrative structures built by the Civilian Conservation Corps.

Responsibility	Activity/Product	Study Topic/Decision	Example
		Forest Service Administration	
Research Station	Overview	CCC (National)	
	Overview/ Monograph	CCC (Forest)	
	Topical History	Specific Area/Topic	Ashdale Ranger Station, Tonto NF
		Structure identified	Barn, built 1935
	Architectural Record	Site Inventory	Reversible alterations
Research Station			
	Evaluation Criteria	Preservation/ Interpretation	
or	National Register Nomination	Evaluation w/SHPO	
Forest	Stabilization/ Restoration/ Interpretive Plan	Evaluation w/SHPO	
	Stabilization/ Restoration		
Forest	Maintenance Plan	Adaptive reuse and/or public interpretation	

organize the RWU's research. These are: ECONOMICS: mining, ranching, homesteading, logging, hunting, trapping, fishing, gathering, trade/commerce, tourism/recreation, transportation, manufacturing. RELIGION: European and Native American practices; and, POLITICAL AND SOCIAL ORGANIZATIONS: Forest Service administration, watershed management, military operations, community development, law enforcement, and ethnic relations.

METHODS AND TECHNIQUES

The full battery of methods and techniques available to historians, architects, and archeologists would be employed. These would include at a minimum: archival research, oral history, inventory survey, excavation, chronological study, architectural analysis, and data base/information management.

Analysis would be strongly oriented toward the following:

1. Studies of material culture as indicators of function, time, technology, and social context.

2. Studies of the cultural landscape as both determinant and end product of human settlement.

3. Studies of human interaction with the environment, following the precepts of cultural ecology, and using techniques such as ethnobotany.

4. Studies of human interactions with one another, especially as they involve intrusion of people into the territories of others.

ESTIMATED STAFFING AND FUNDING REQUIREMENTS

The objectives of the plan could be met through the establishment of a Unit for Historical Research, located within the National Forest Southwest Region. The Historic RWU would involve an overall staff as follows, including a combination of key core positions marked with an asterisk (*), and shared service positions from existing programs and from partnerships with other Federal agencies (e.g., BLM and NPS). Project-specific positions would be brought in under a cooperative agreement and/or contract services.

Project Leader
Secretary
Clerk Typists (2)
Historian *
Ethnohistorian *
Historical Archeologist *
Curator
Archivist/Librarian
Interpretation Specialist
Conservator
Writer/Editor

The normal amount of floor space and equipment would be required. Annual budget projections are as follows:

Personnel compensation and benefits	$532,000
Travel and transportation of persons	50,000
Transportation of things	1,500
Supplies and materials	40,000
Contract services	200,000
Overhead (rent, utilities, etc.)	300,000
Total:	$1,123,500

Forest Service personnel may wish to examine this plan and develop a phasing proposal for implementation. Our recommendation for initial funding would target the filling of key core positions within the existing Experimental Station framework. The plan recommends a three-year phasing period.

As the RWU is developed a priority research program for the Southwest Region and Rocky Mountain Station Service Area should be initiated to provide contextual criteria for the evaluation and interpretation of historic sites through topical overviews and inventories to be produced cooperatively between National Forest Service Units and the Rocky Mountain Station, with the Station focused primarily on the production of overviews.

Recommended priorities for the suggested topics are:

1. SPANISH COLONIAL HISTORY FOR THE 1992 CHRISTOPHER COLUMBUS QUINCENTENNARY OBSERVANCE. Justification: the Columbus Quincentennial commemorating the 500th year anniversary of the encounter between Indian America and Europe offers the Forest Service a national and international opportunity to justify historical overviews, inventories, and surveys of Spanish Colonial sites on Forest lands. Additional opportunities for CRM and interpretation activities should include pending bills in Congress related to the Coronado Trail Study Bill and the Spanish Colonial Settlement Commemorative Bill, which may include historical sites on Forest Service lands.

2. LATE NINETEENTH AND EARLY TWENTIETH CENTURY NATIVE AMERICAN USE OF FOREST LANDS. Justification: legislative mandates such as the American Indian Religious Freedom Act, and recent Native American interest in asserting rights to traditional land use, require that Federal land management agencies be knowledgeable about the uses that have persisted in actuality as well as tradition among Native American peoples so as to be able to deal equitably with them.

3. FOREST SERVICE BUILT ENVIRONMENTS. Justification: facilitate better management, maintenance, and interpretation of Forest Service facilities. A historical overview is recommended.

4. MINING. Justification: facilitate project-specific compliance and management of this important historic resource. An historical overview and inventory are recommended.

Toward a More Rational Management of Cultural Resources[1]

Linda Marie Lux[2]

Abstract.--The USDA Forest Service needs a process for deciding which historic properties to preserve and manage, a logical system of decision-making based on scientific principles of management, and using simple, efficient procedures. Two methods--comprehensive planning and research design--have been proposed, and are being used in the Pacific Southwest Region of the Forest Service in California. A Forest Service research program for cultural resources could help refine these two methods.

INTRODUCTION

In the USDA Forest Service, cultural resource management protects historic properties from damage or destruction by traditional activities on the National Forests. The agency annually conducts nearly 6,500 individual surveys, examines 1.5 million acres, and identifies more than 8,000 new cultural properties. To date, 18 million acres of National Forest land have been surveyed and 125,000 cultural properties have been located, mapped, and recorded. This number of recorded properties, then, has been increasing at a rate of more than 8,000 per year.

Historic preservation is a tripartite process--identification, evaluation, and management. Overall, the Forest Service has done an admirable job of identifying historic resources, but we have only begun to move beyond this first step. Only 15 percent of all inventoried sites have been evaluated to determine their historic importance or potential to yield research data. Until we can evaluate sites, how can we decide what to manage and protect?

The National Register criteria provide some guidance for evaluating significance, but they cannot provide the detailed rationale that is needed (Raab and Klinger 1977). When evaluation does take place, it is often done on a case-by-case basis without the benefit of knowing the resource's relative importance in the larger picture. Determinations of significance are based on experience and observation, empirical thinking, but not a comprehensive, rational plan. Evaluation has been almost negligible, and most properties are simply saved, categorically, with little opportunity for considering the full range of management alternatives. Important cultural resources may even escape recognition and protection.

Historic preservation laws require that cultural resource surveys be conducted in preparation for all other land management activities. Forest Service cultural resources programs have tended to focus on this compliance aspect of our responsibilities. This means that surveys are conducted in a piecemeal fashion rather than as part of planned regional programs with direction and logic of their own. As a result, within the agency, cultural resource management is often seen simply as responding to laws and regulations. The professional and scientific community perceives the Forest Service as collectors of masses of unsynthesized information. Caught up in the race to keep ahead of the bulldozers and timber sales, we seldom have time to reflect on more effective, efficient ways of managing cultural resources.

We can no longer afford to defer the process of evaluation. We cannot continue to accumulate site records at a rate of 8,000 per year without effective means of managing and protecting them. The Forest Service needs a process for deciding what historic resources to preserve, a logical system of decision-making that is based on scientific principles that uses simple, efficient procedures. We need to design a more rational approach to cultural resources management. Then, and only then, will the program become fully integrated into the land management process, and at the same time fulfill its potential to contribute to research. There are solutions and those solutions have been evolving for some time now.

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[1] Paper presented at the symposium: Tools to manage the past: Research priorities for cultural resources management in the Southwest. [Grand Canyon, AZ, May 1-6, 1988].

[2] Linda Marie Lux is an Historian, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

This paper reviews two methods that have been proposed for rationalizing the process of gathering data and making historic preservation decisions, and describes how comprehensive planning and research design are being used in the Pacific Southwest Region of the Forest Service in California. It then discusses ways in which a Forest Service research program for cultural resources might improve and refine these methods.

COMPREHENSIVE PLANNING

In 1980, the Heritage Conservation and Recreation Service published the controversial Resource Protection Planning Process (RP3). RP3 was an attempt to rationalize historic preservation and streamline historic preservation programs while satisfying research data needs (Aten 1982). Its stated purpose was:

> To develop a comprehensive historic resource management process which identifies and organizes information about a State's historic, archeological, architectural, and cultural resources into a form and process readily usable for producing high reliability decisions, recommendations, and/or advice about the identification, evaluation, and protection of these resources (Heritage Conservation and Recreation Service 1980).

RP3 had three components: study units, operating plans, and management units. A study unit consisted of a group of historic resources defined by three common elements: theme, time, and space. An operating plan transformed the technical data from the inventory and evaluation of these study units into a program for managing the resources. Finally, management units formed the link between historic preservation and the agency's broader mission and goals.

Early in its development, RP3 met with resistance on the state planning level, and after a series of political failures and miscalculations it lost some of its momentum (Scarpino 1988). The greatest weakness of RP3, however, can be attributed to the way in which it was applied. Emphasis was placed on study units, while operating plans and management units were poorly developed. The study units provided a framework for data collection, but by themselves, lack integration of this information into the agency's planning process. Historic preservation has, therefore, remained isolated, outside the larger process (Tamez 1988).

Nevertheless, when all components of this process are fully developed, the method may provide a solution to many of our problems. Over the last decade, RP3 has been refined, and it is now emerging as the standard for historic preservation planning. The Secretary of the Interior's guidelines for Federal responsibilities, under Section 110 of the National Historic Preservation Act, describes a comprehensive planning process that is basically identical to RP3 (National Park Service 1986). In this model, historic preservation begins with the establishment of historic contexts (essentially the RP3 study units and operating plans). These contexts include the development of preservation goals and management priorities.

In a fully-developed form, historic contexts include:

- A rationale based on theme, time, and place
- Descriptions of known and expected resource types
- Their known and expected distribution
- Evaluation criteria
- Research and documentation needs
- Operating plans describing survey strategies, and management alternatives

These elements are then linked to a management plan which incorporates historic resource planning into the agency's property management, land-use planning, and project planning.

The contextual history drives every aspect of historic preservation: surveys, evaluation, management, even nominations to the National Register. This comprehensive planning process is reflected in the new multiple property form for National Register nominations, which is now a planning document in itself. In the new multiple property form, an historic theme is described and placed in both time and space. Property types are also defined. For each of these property types, a basic description, statement of significance, and registration requirements are included. Later, individual buildings, sites, and districts are nominated under this historic context. The process forces us to view historic properties as parts of larger systems and allows for comparison, rather than focusing solely on the inherent characteristics of isolated resources to determine their value.

REGIONAL RESEARCH DESIGNS

Research design is the second method that has been developed as a means of clarifying theoretical goals and defining ways in which these goals can be realistically achieved. A research design:

- Defines the universe of study
- Provides a rationale for the intended work
- Identifies important questions and problems to be investigated

- Describes the methods to be used for data recovery and analysis
- Shows how the methods relate to stated aims and help to determine significance
- Sets forth realistic expectations for the research
- Provides a mechanism for disseminating the results of research to the public

By the 1970's, it had become clear that we needed a way to deal with the growing conflict between salvage archaeology and long-range research programs (Goodyear 1978, King 1971, Schiffer and Gumerman 1977, and others). More and more, surveys were being conducted to mitigate land disturbing activities, yet, early on it was argued that it was possible to develop large-scale, long-range regional research programs so that these projects could contribute to research designs (King 1971). These earlier discussions focused on research designs for prehistoric archaeology, but clearly a similar perspective was needed for historic resources. Today, cultural resource management continues to be driven by other priorities, and the need for research designs is perhaps even greater.

As contrasted with more intuitive approaches, research designs lead to efficient, cost-effective work because they maximize the yield of relevant information (Moratto 1981). They also permit the evaluation of research findings in terms of explicit criteria (Brown and Elling 1981; Goodyear 1978; Shiffer and Gumerman 1977). The formulation of major research questions and the construction of alternative hypotheses can provide a new focus for cultural resource programs and ensure that they contribute to the discipline.

MERGING HISTORIC PRESERVATION AND RESEARCH DESIGN

To remedy the difficulties inherent in the management of cultural resources on a case-by-case basis, the Pacific Southwest Region of the Forest Service is developing a series of regional, thematic comprehensive plans. By presenting a regional perspective, we are emphasizing research problems common to a broad, geographical area. A cultural theme focuses on a particular type of historic activity, land-use, or property type.

In 1986, the Forest Service joined with the Califonria State Historic Preservation Office and other Federal agencies to identify resource types to be developed in the initial effort. We sought property types frequently encountered throughout the region, that shared a common theme and physical characteristics. The property types we chose can be evaluated and managed using standardized guidelines. Pioneer studies such as the Forest Service plan for Civilian Conservation Corps buildings in the Pacific Northwest Region (U.S. Department of Agriculture 1983) and the California Department of Transportation's study of truss bridges (1983) were used as models.

The Forest Service chose to develop comprehensive thematic plans for the following types of properties: railroad logging sites (U.S. Department of Agriculture 1987a), fire lookouts (U.S. Department of Agriculture 1987b), Forest Service administrative buildings (U.S. Department of Agriculture 1988a), western mining sites, and recreation residences (U.S. Department of Agriculture 1988b). We are also participating in interagency teams to develop thematic plans for isolated bedrock mortars, sparse lithic scatters (Jackson 1988), and tin can deposits (U.S. Department of Agriculture 1988c). Clearly, the approach can be used to organize a wide range of property types, both historic and prehistoric.

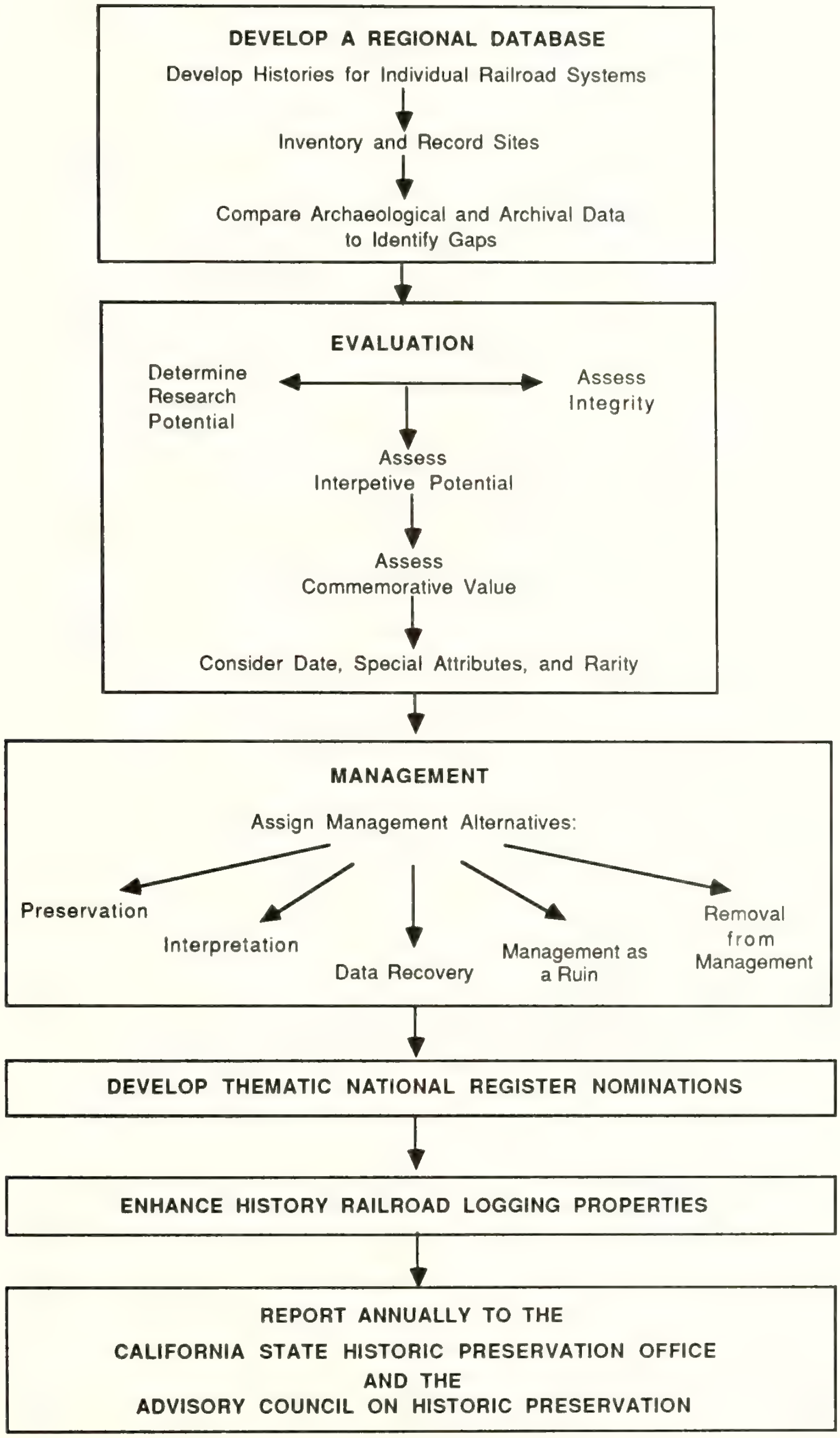
The plan for railroad logging sites merges the two methods, comprehensive planning and research design, to satisfy both historic preservation and research needs. An outline of this plan will demonstrate how these methods are integrated. The three elements of the study are its cultural concept--historic railroad logging systems, its chronological limits--1860 to 1940, and its geographic limits--California's National Forests; theme, time, and place.

The plan consists of three interrelated parts: a regionwide contextual history, a management plan, and a research design. The contextual history provides an overview of railroad logging in the State and, by defining the importance of this theme in California history, provides a rationale for the study. The management plan describes the process for gathering and synthesizing pertinent data, provides evaluation criteria, and describes a process for choosing management options for these resources. The research design poses regional research questions in four broad areas: economics, technology, environment, and sociocultural dynamics. The three documents are thoroughly interrelated so that evaluation and management are justified by the regional history and driven by the perceived needs generated in the research design.

The management plan is an important element and moves the process from simple data collection to evaluation and management decisions. The first phase of the management plan is to develop a regional data base. Under the larger regional history, more specific histories are compiled that provide descriptions of individual logging railroad systems. Within each system, all known, recorded sites are identified. The archaeological data are then compared with the contextual histories and archive records to identify problems, such as gaps in the information.

In the second phase, the data base is used in conjunction with the research design to evaluate the significance of a site. Properties are assessed for their potential to answer the

PACIFIC SOUTHWEST REGION'S RAILROAD LOGGING COMPREHENSIVE PLAN



regional research questions outlined in the research design, and to fill the identified gaps in the historical record. The integrity, interpretive potential, and regional and local commemorative values of the property are also assessed. Factors such as date of construction, special attributes, and rarity are considered to ensure that a temporal cross section of railroad logging sites is preserved as well as properties that are unique. To some extent, these criteria relate to National Register criteria; however, the emphasis here is on choosing management alternatives.

In evaluating railroad logging properties as a thematic group, their regional significance becomes more apparent, and a choice of appropriate management alternatives is facilitated. Five alternatives are defined in the management plan:

- Preservation
- Interpretation
- Data recovery
- Management as a ruin
- Removal from management consideration

The goal in chosing among these is to ensure that a representative group of railroad grades, associated sites, and features are preserved--sites that possess integrity, are historically significant, and/or have potential to yield important research data.

Finally, the Forest Service will actively engage in enhancement activities. The contextual history and research design facilitate a multiple property National Register nomination. Railroad logging properties can be nominated based on regional criteria and documented as to their importance within California's history. The Forest Service will encourage historical and archaeological research in areas where high risk to railroad logging properties exists, but as part of broader, regional historic preservation objectives. These sites will be considered equally with other resources on the Forests; and their management will be integrated into the other functions of the agency.

Although it might be desirable to implement the plan simultaneously throughout the Pacific Southwest Region, that is not practical. Instead, the plan will be developed on a Forest-by-Forest basis, throughout the Region's 18 National Forests, over the next several years. The comprehensive plan is a dynamic, changing document that will be updated periodically to reflect advances in theory, method, and knowledge, as the data base develops.

Because of their complexity, railroad logging sites pose a unique challenge in comprehensive cultural resource planning, and should prove a formidable test of this approach. Here, we are not addressing discrete property types such as bridges or administrative buildings but, rather, a complex, production-oriented system. Yet, as with the more easily-defined property types, we can treat these complex systems in a consistent manner. The comprehensive plan provides standards and guidelines for this process.

REFINEMENT OF THE PROCESS

Application of the comprehensive planning approach is still in its early stages, and as the contextual histories and research designs are implemented in the field, the need for refinement of the process will undoubtedly arise. At this point, there are several areas where more knowledge would increase the effectiveness of the process and where Forest Service research might contribute to this effort. We need:

- Criteria to determine what data capture a property's essential character and its relation to its environment, to ensure that cultural resources contribute to the solution of research problems. A base level of scientific observation needs to be defined.
- Methods to determine historical significance that reduce bias. Criteria for evaluation often seem subjective to those unfamiliar with the goals of historic preservation. One approach would be to ask a group of resource specialists to rate a thematic group of sites, compare results, and identify the areas in which ratings are most consistent.
- A system for classifying research problems and developing regional research designs that are comprehensive enough to evaluate the significance of any site within a given region. Our knowledge is still limited in some areas of study, and research problems are not always clearly defined.
- Criteria for determining what constitutes a representative sample that will meet future needs. A comprehensive approach is dependent on current technical, methodological, and theoretical knowledge, therefore, it is important to preserve representative samples.
- Automated data base systems to assist with data collection, track evaluation and management decisions, and facilitate research.
- More effective methods of integrating historic preservation goals into the larger planning process. Managerial and technical options need to be presented in a form that can be understood, accepted, and applied by others in the organization.
- A process to quantify rates of resource loss and determine how to compensate for this in comprehensive planning; a means to measure the

adequacy or inadequacy of present protection systems.

- Refinement of the comprehensive planning process so that it addresses questions about "how" and "why" cultural systems vary through time and space. A process for relating the various themes may, in part, accomplish this objective.

- Methods for evaluating resource interpretation, and for ensuring that a diversity of people are identified in our interpretation of the past.

BENEFITS TO THE RESOURCE

This broad, regional approach has several advantages. Most important are the benefits to the resource. We simply cannot do justice to these historic properties until we can evaluate them in a comprehensive framework. An isolated artifact has little or no research value when taken out of context. Similarly, an isolated railroad grade or logging camp has limited potential to yield information when taken out of its historical context.

This approach will also enable National Forest Archaeologists to advance beyond the inventory process, to evaluate and manage historic sites. Comprehensive planning will provide these resource managers with the criteria needed to make important decisions, such as which sites to preserve.

A third benefit will be savings in time and dollars. The present system of evaluating properties is time consuming, and can even result in the unnecessary loss of the resource before research information has been documented, or the potential for interpretation or commemoration assessed.

Comprehensive planning has great potential. Management of the resource with larger, regional concerns in mind will ensure that research and data needs are met, and that these resources will be accessible for future study and for public appreciation.

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Planning for Obsolescence in Integrated Research[1]

Joseph A. Tainter[2]

Abstract.--Forest Managers should undertake integrated cultural resources research with a prior understanding of what such a program can accomplish, and what it cannot. This paper addresses limitations in integrated research designs, and recommends ways to accommodate these limitations.

INTRODUCTION

One of the challenges of representing a scientific discipline in a land-managing agency is explaining technical matters to line and staff officers. No doubt all specialists share this problem, for there is a mystique about science which can be difficult to overcome. The public thinks of science as dealing in concrete facts, as a definitive, rational endeavor, and as producing cumulative findings. There is an implicit assumption that if society invests long enough in science, some day the universe will be fully understood, the scientists can be pensioned off, and the results turned into useful products. Those who practice science often suspect the opposite: that facts are relative to perception, that scientific truth is a political consensus, and that scientific change is as likely to be revolutionary as cumulative. Long before the universe is fully understood we will reach the point where we cannot afford to learn much more.

A program of scientific research in a land-managing agency will have both benefits and pitfalls. Perhaps the greatest pitfall is in the expectations of non-specialists about the nature of such a program and what it can produce. Those who manage parcels of National Forest will expect concrete results from our research. These managers, in my experience, often view archeology with the same misconceptions that guide public perceptions of science overall. These misconceptions may be too ingrained ever to correct, but the matter at hand is too important not to make the attempt. A cultural resources research program would benefit forest management, but we should estimate beforehand what those benefits might be, as well as what they cannot be.

My topic is integrated research designs, but the comments I will make are pertinent to all aspects of planning a research program.[3] My points are:

1. The importance of an archeological or historical site is neither intrinsic nor permanent.

2. Contrary to its public image, science is not exclusively a rational, cumulative process.

These first two points, as I will explain, limit how an integrated research design can be used for on-the-ground management.

3. There is a tendency toward inertia in both government and science. In planning a research program we must recognize that this is inevitable, and consider how it affects the dynamic nature of research.

4. Scientific research reaches a point of diminishing returns. Research is an economic investment: it has costs and yields benefits, and the benefit/cost ratio is not static.

The discussion of these points will be clearer if I begin by outlining the nature of integrated research designs.

INTEGRATED RESEARCH DESIGNS

As used in cultural resource management, a research design specifies what is known about the past occupation of a region, and what important things remain to be learned. The assumption is that the value of an archeological or historical site cannot be determined in isolation. That value can only be found in the relationship of a site to other sites, and to an overall body of knowledge.

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[1] Paper presented at the Forest Service Cultural Resources Research Symposium (Grand Canyon, May 2 - 6, 1988).

[2] Joseph A. Tainter, Archeologist, USDA Forest Service, Cibola National Forest, Albuquerque, N.M.

[3] For more detailed discussions of these points see Dunnell (1984), Tainter (1988: 99-106, n.d.) and Tainter and Lucas (1983).

Those who support a research-based approach to management argue that research designs can accomplish several things. These include: (a) providing a basis for assessing individual sites; (b) ensuring agreement about preservation goals and fieldwork standards; (c) requiring that substandard work be improved; (d) establishing excavation priorities among threatened sites; (e) providing objective decision-making criteria that can be used to resist political pressures; and (f) developing understanding and support among non-specialists (e.g., T. King 1971, 1977; McMillan et al. 1977; Nickens 1980; Raab and Klinger 1977; Wendorf 1980; L. King 1980; Comptroller General 1981). To the extent that any site may yield information pertinent to the research design, decisions can be made about preservation or study, methods of accomplishing these can be specified, and support can be developed in the public arena.

Yet integrated research designs that are thoughtlessly developed or applied will bring more harm than benefits. Thus it is necessary beforehand to discuss research designs within the context of the four points I have raised.

THE IMPORTANCE OF SITES

From its very earliest years the historic preservation movement in this country faced an embarrassment of riches. There were far more worthy properties than there were time or money to save them, and ways had to be found to determine which merited attention (Hosmer 1965). Preservationists have dealt with this concern for at least a century now, and at least one lesson is clear: if there was an easy answer to the problem of rating the importance of sites we surely would have found it by this point.

Many professionals believe that the research design can solve this problem, at least for archeological properties. As a research design specifies what important things are to be learned about history or prehistory, it will also specify what kinds of data are necessary to learn these things. An archeological site can then be evaluated by whether it is likely to yield information pertinent to the research design.

Many archeologists have found this argument disarmingly attractive. It is simple and clear, and seems to provide an easy answer to a convoluted problem. A peek under the surface, however, reveals that it solves current management problems by short-changing the future. As an approach to managing immediate impacts (e.g., strip mining) the research design is commendable. An an approach to long-term management, however, it has crippling defects.

The problem is that the federal regulations (36 CFR 60.4), and many managers, assume that the importance of a site is intrinsic and permanent (Tainter and Lucas 1983: 710-711). We know, however, that scientific disciplines change, often quite radically (Kuhn 1970; Willey and Sabloff 1974; Dunnell 1984). As any science changes it asks new questions that require new kinds of data. If archeological sites are rated by how they may contribute to solving research questions, then clearly that rating cannot be permanent. As states of knowledge and theories inevitably change, in archeology as in any science, the importance of individual sites will change also. Significance is not inherent or immutable. It is not a part of the cultural property, but is in the eye of the beholder. A site is never permanently significant or insignificant to science (Tainter and Lucas 1983: 714-715).

THE POLITICS OF SCIENCE

My second point is that science is not exclusively a rational, cumulative process. Decisions are made in science, as in any human endeavor, in a matrix of social relations and political maneuvering.

Until the mid to latter part of the nineteenth century science was generally the province of the gentleman-amateur, who was typically a wealthy dilettante pursuing individual studies in natural science. The image that emerged at this time - the lone-wolf natural scientist - is a powerful one, and perseveres to this day in our national mythology. It is strongly reflected in media presentations, where scientific findings are depicted as the accomplishments of heroic individuals who grapple with a recalcitrant universe that yields its secrets to ingenuity and persistence. Science, in this myth, progresses by the efforts of many thousands of Sherlock Holmeses, each pushing back the frontiers of knowledge by doing things like slashing through Amazonian jungles or peering long hours through lonely telescopes.

However romantic this vision, it has not been accurate for some time. Long ago, growth in the size and complexity of science required the development of learned societies, research institutions, and interdisciplinary teams (Price 1963). Science today is so institutionally organized that it is the subject of an entire subdiscipline of sociology (e.g., Merton 1973; Blume 1974). As social scientists we should not be surprised by the findings of this school, although they are something that we don't consider often enough. The sociologists remind us that science today is a social and political process. A scientist rarely practices alone anymore. He or she is usually part of a community of scholars, and is subject to all of the pressures and influences that operate in any human community. As in any social unit, the members of a scientific community are linked by common experiences in education, apprenticeship, ethical standards, shared goals, communication, and agreement in many matters of professional judgment (Kuhn 1970: 177-178, 1977: 296; Dunnell 1984: 63).

Although we commonly think of scientific findings as emerging from the rational application of scientific methods, a sociologist of science would reach a different conclusion. That which passes as scientific knowledge, in the sociological view, is a political consensus: "...empirical truth," asserts one sociologist, "is affirmed through agreement" (Blissett 1972: 94).

A scientific observation becomes enshrined as a textbook principle through a political process. This is admittedly not a frequently-heard assertion, but it is easy to show that science must be so. To begin with, no scientific finding is of any value unless it is socially recognized - and this means that it is affirmed by the scientific community. Secondly, in the absence of a social consensus all facts are equally important. The consensus principle reduces the chaos that would exist if every idea was welcomed equally. And thirdly, a scientific consensus focuses inquiry, directing attention to some small aspect of nature that could not otherwise be studied in such detail. There is no way without a consensus to focus research (Kuhn 1970: 24; Barnes 1982: 7; Blissett 1972: 95-97, 100, 102; Ziman 1968: 18, 55).

A scientific discipline, like any social system, can maintain itself only with mechanisms that select for and perpetuate its consensus. These range from subtle selection and training to peer pressure to outright political manipulation. Experienced scientists know that to make their contributions acceptable they must maximize the agreement that they can reach with their peers.

Developing integrated research designs is a process of engineered consensus in which the political element will be manifest (Tainter n.d.). The research designs that emerge will be ones that have survived multiple political trials. They must have broad professional support; they must seem worthwhile to a majority of a region's archeologists; and they must appear more important than a host of competing ideas. While scientific rationality will certainly be important in designing integrated research, it will not be the only factor, or even the dominant one. Integrated research designs will be primarily the product of negotiation and political consensus. This in itself is not a matter for concern, except insofar as we use short-term political considerations to make long-term preservation decisions.

The two points discussed so far - that importance is an assigned quality and that designing joint research is a political process - limit what we can expect to accomplish with integrated research designs. The importance or significance of a site is not inherent, but is assigned in the context of consensual science. Significance can never be immutable, for neither are scientific frameworks. As a temporary political arrangement, a scientific consensus will be a poor basis for what will often be irrevocable preservation decisions.

Integrated research designs are a marvelous idea, and they have the potential to accomplish much. They will allow agencies to implement a common approach to such areas as research, public interpretation, stabilization, and mitigation. The one thing that they will not do is give us guidance for deciding which sites to preserve and which not to. Research designs emerge from scientific frameworks, and we know that today's scientific frameworks will change. We also know that today's scientific consensus is based on short-term political considerations. It seems unavoidable to conclude that preservation decisions cannot emerge from an integrated research design.

INERTIA

Both government and science (McCain and Segal 1973: 150) are characterized by a level of inertia that is not propitious for integrated research designs. Government pronouncements today may no longer be written in stone or on clay tablets, but they seem often to achieve a similar longevity. One of the main pitfalls of government-sponsored research designs is the possibility that, once formulated, research designs may be very hard to change.

It is possible that integrated research designs will fail utterly to respond to the dynamic nature of science. The main potential for a problem lies with non-specialist managers, who must struggle with many competing demands and find the scarce funds to support cultural resource management. These persons often know little about science beyond the popular myth that it is rational and cumulative. The tendency of managers will be to think that once they have funded integrated research designs the job will be done, and they need not plan for future spending in this area. Our challenge is to explain that scientific disciplines change constantly, that change is often revolutionary, and that developing integrated research designs is a task that will never end. Many managers, in my experience, will not like to hear this message.

The second concern under the heading of "inertia" has to do with economics. The experience of agencies that fund basic research is that it is less expensive to continue an established line of research than to start a new line (Blissett 1972: 98). We should not expect that the economics of research in the Forest Service are any different. Once research suggested by an integrated design is under way it will tend to foreclose other lines of study. There is no easy answer to this problem, and I raise it only to point out that several factors may converge to produce the same undesirable outcome: integrated research designs that cannot keep abreast of current developments.

ECONOMICS OF RESEARCH

The final consideration I wish to raise has also to do with economics. It is generally unrecognized, but nonetheless true, that scientific studies tend to reach a point of diminishing returns. This is, of course, characteristic of economic investments in general. In science, diminishing returns set in when higher costs - for such things as laboratories, equipment, or salaries - are not matched by proportionate returns in knowledge (Rostow 1980: 171; Rescher 1978, 1980; Tainter 1988: 99-106). The marginal return to the investment declines as a unit increase in expenditures yields less than a unit increase in knowledge. One implication is that exponential growth in the funding of research becomes necessary simply to maintain a constant rate of progress (Rescher 1980: 2).

There are anecdotal incidents from archeology to illustrate this tendency (e.g., T. King 1981), but there are better, quantitative illustrations from other fields. Medical research and application provide a good example of diminishing returns in a scientific field. Ever greater investments in health care do not yield proportionate increases in life expectancy. In 1930 the United States allocated 3.3 percent of its gross national product to produce an average life expectancy of about 60 years. By 1982, 10.5 percent of GNP was being invested to produce a

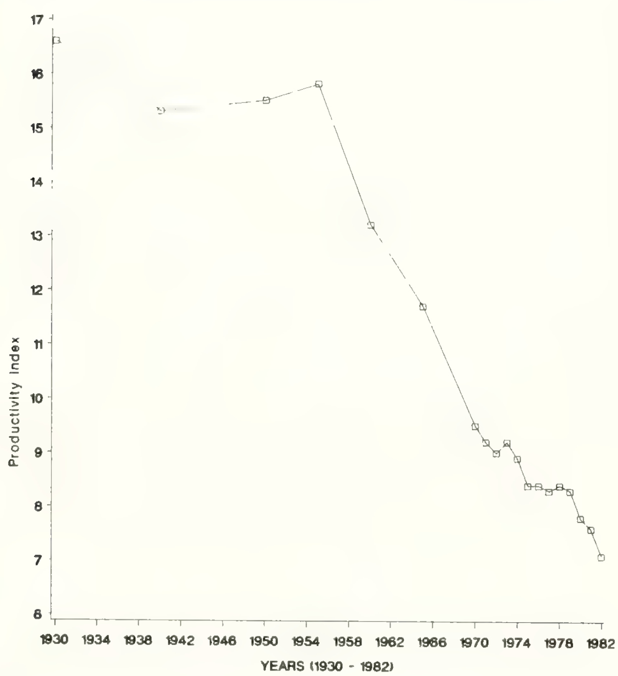

Figure 1.--Productivity of the U.S. health care system, 1930-82 (after Tainter [1988: 103]; data from Worthington [1975: 5] and U.S. Bureau of the Census [1983: 73, 102]). Productivity Index = (life expectancy)/(national health expenditures as percent of GNP).

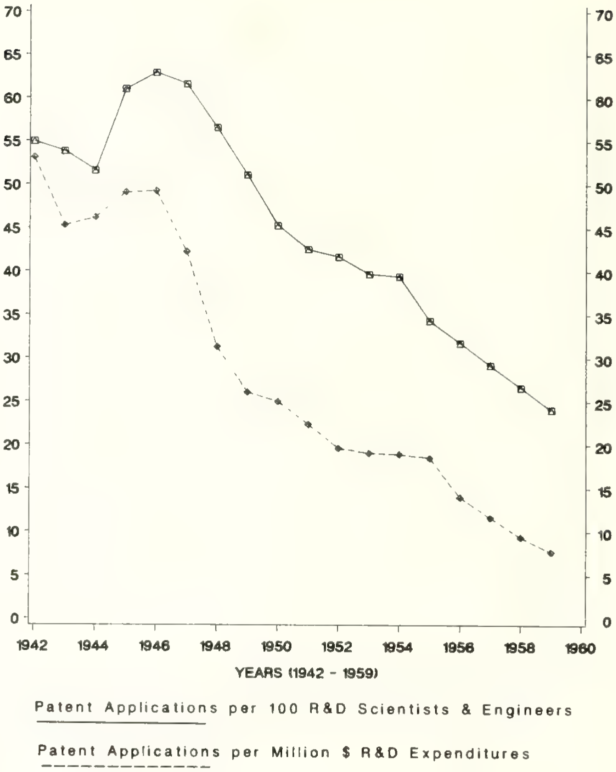

Figure 2.--Patent applications in respect to research inputs, 1942-59 (after Tainter [1988: 101]; data from Machlup [1962: 173]).

life expectancy of about 75 years. The pattern in the intervening decades is shown in figure 1. It can be seen that from 1930 to 1982 the productivity of the U.S. national health care system declined by over 57 percent (Tainter 1988: 102-103).

One philosopher who has studied this matter is Nicholas Rescher (1978, 1980). He suggests that

> Once all of the findings at a given state-of-the-art level of investigative technology have been realized, one must move to a more expensive level.... In natural science we are involved in a technological arms race: with every "victory over nature" the difficulty of achieving the breakthroughs which lie ahead is increased (Rescher 1980: 94, 97).

This problem is not restricted to individual disciplines; it pervades science as a whole. Figure 2 shows that as the resources committed to scientific research have grown in recent years, the productivity of these resources for producing patentable inventions has declined noticeably.

Diminishing returns to research are normal, and mark a discipline that has reached a level of

intellectual sophistication where it can ask questions that are difficult and costly to answer. One would not want to advocate undertaking only studies with a high ratio of findings to costs. In archeology this would limit us to asking primarily factual questions on the level of What, When, and Where. Yet any science that relies on public funding exposes itself to misunderstanding when it undertakes costly research that has an uncertain return.

Once again we are brought back to the conflict between managers, who ordinarily are not experienced in subtle economic trends, and specialists, who must justify constant requests for greater funding. This conflict is clearly evident in archeological survey. Managers try constantly to restrain the cost of finding sites, and typically ask why it is not sufficient to find most of the sites in an area. Some archeologists, in contrast, argue for the opposite: that we need to locate not only every site, but every isolated artifact.[4] The latter approach would be a classic case of diminishing returns: very high costs, quite uncertain results, and a benefit/cost ratio that few managers could accept.[5]

Integrated research, and all aspects of the program under consideration, will reach the point of diminishing returns. At this point those who control the purse will be tempted to phase out the program, reduce its scope, or change its focus. The problem will be that this is the point where our research will have passed its initial phases, and is finally starting to investigate topics of genuine merit. It is important to remember that in an environment of diminishing returns, the difference between a constant budget and a declining one is only a matter of degree.

SUMMARY OF CONCERNS

In summary, I believe that both specialists and managers need to recognize the following points before we proceed to develop integrated research designs.

First, a research design provides little or no basis for making irrevocable preservation decisions. Significance is not intrinsic to sites; it is assigned in the context of research frameworks. Any system of rating sites through integrated research designs will be based on short-term political considerations, not - as is often believed - exclusively on rational logic. To use an integrated research design to decide which sites to preserve is to do an injustice to our data base. Preservation decisions cannot emerge from an integrated research design.

Secondly, we must be alert to the possibility that, once in place, research designs may be very hard to change. The inertia of government and science, and the economics of funding new lines of research, will tend to cement in place whatever research topics we begin with. It is for this reason that many archeologists are reluctant to accept integrated approaches.

Finally there is the matter of diminishing returns to research. This problem may work in a direction counter to the last, for as a line of research becomes costlier and produces more infrequent breakthroughs, managers will be tempted to curtail it or shift study to other topics. This may happen just as we get to the point where we are finally able to ask interesting questions.

RECOMMENDATIONS

This has been a pessimistic appraisal. Yet I raise these points not to be a naysayer - I fully support integrated research - but to suggest that the Forest Service approach this matter with a dose of realism. When the agency first started to take seriously its cultural resources responsibilities, most line and staff officers did not know what they were getting into. This mistake has led to much misunderstanding over the years, something I do not want to see repeated when the agency undertakes a new research mission. A judicious program of cultural resources research will benefit historic properties, multiple-use management, and the agency's public image, and integrated research designs could profitably be pursued in such a program. Yet archeologists and managers alike will be much more satisfied if we design the program to avoid the pitfalls I have described. I will conclude with some proposals for how to accomplish this.

The most important matter is for both specialists and managers to understand at the outset what integrated research designs can accomplish and what they cannot. I see the main benefits being as follows:

- focusing the work of many agencies on common scientific goals, thereby ensuring a concentrated effort in addressing research questions;

- coordinating programs of public interpretation, so as to avoid both gaps in coverage and duplication of effort, and ensuring the most effective use of resources;

- developing a common pool of background knowledge, thus maximizing the investment in professional expertise;

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[4] E.g., Camilli, Eileen L., Signa Larralde, and John Roney. n.d. Navajo-Hopi land exchange archaeological project interim report. Report on file, Bureau of Land Management, Albuquerque District Office, Albuquerque, N.M.

[5] Tainter, Joseph A. 1987. A framework for understanding the evolution of survey methods in cultural resource management. Paper presented in the symposium "Low Density Archaeological Phenomena" at the Fifth Jornada Mogollon Conference, Human Systems Research, Tularosa, N.M.

- coordinating efforts in archeological survey, so that arbitrary patterns of land ownership do not restrict our data base to the extent which is now the case; and

- providing a common approach to mitigation where site destruction is unavoidable, ensuring that mitigation studies produce coordinated rather than idiosyncratic results.

This list suggests that integrated research designs will produce enough worthwhile tasks to keep all of us happy and busy for some time. When we must decide whether or not a site merits long-term preservation, however, we cannot turn to a research design to find the answer.

Among the preservation plans that I have seen - and I have read a great many (Tainter n.d.) - the common approach seems to be that once the planning document is complete, attention can be turned to other matters. Given the many pitfalls in cultural resources planning this is a short-sighted approach. If we undertake to develop integrated research designs, it should be with the expectation that this is a process with no end. As scientific frameworks and the costs of research change, so also must the research designs that guide management. Scientific and economic change must be anticipated and provided for. An integrated research design will be worthwhile only if there is a commitment to undertake continuous development and constant revision, and to provide the funding that this will require.

The last recommendation concerns staffing. Most archeologists, both in and out of agency employment, are harried, overworked individuals who deal constantly with pressing matters. In my experience, such persons will routinely put abstract planning tasks to the bottom of their priority list, below the unavoidable demands of day-to-day business. This is a matter of necessity, whatever the archeologist's personal inclination. What this means is that we cannot simply provide good will and funding for continuously developing research designs. These by themselves will not get the job done. It will also be necessary to assign a specific person to the task, a person who has no higher responsibilities. Not the least of this person's concerns will be to explain why the research reaches diminishing returns: why costs go up and up for research that seems ever more esoteric.

Clearly, then, integrated research designs will require a significant and ongoing commitment of resources - a commitment that we must acknowledge and measure beforehand. If we cannot make this commitment at the outset then we should not undertake the task at all. If we decide that the costs of such a program are too high compared to its benefits then it would be best simply to drop altogether the idea of integrated research. A partial effort in this area may do more harm than good, and a management effort that is idiosyncratic and chaotic is to be preferred to one that is systematic but short-sighted.

ACKNOWLEDGEMENTS

Thanks are due, as always, to my wife, Bonnie Bagley Tainter, for help in the editing and paste-up of this paper.

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Integrated Research Designs: a Tool to Manage the Past[1]

Evan DeBloois[2], Shereen Lerner[3], Linda Lux[4], John Schelberg[5], Joseph Tainter[6], and David Wilcox[7]

INTRODUCTION

One of the problems of cultural resource management is that it is practiced by dozens of agencies and hundreds of archeologists and managers. The outcome is a bedlam of idiosyncratic programs and results. Rarely is there an opportunity to design a coordinated approach or to synthesize results. The purpose of a program of integrated research would be to deal explicitly with this problem by coordinating the cultural resource management efforts of Federal agencies and State Historic Preservation Offices. This would serve to:

- focus the work of management agencies on common scientific goals;

- coordinate programs of public interpretation;

- develop a common pool of background knowledge;

- coordinate efforts in archeological survey; and

- provide a common approach to mitigation where destruction of sites cannot be avoided.

The term "integrated research" has been chosen to indicate several things. It refers to coordination of research efforts among archeologists and across geographical areas (what is also called a regional research design). It refers as well to coordination of management and research efforts among Federal agencies and State Historic Preservation Offices.

Integrated research should be conducted under the auspices of state historic preservation planning and Forest land management planning. A program of integrated research should be designed to be a link between these planning efforts. A State Historic Preservation Plan is intended to guide historic management throughout a state, while Forest planning is intended to guide Forest multiple-use management. Both levels of planning will be improved if they proceed in a coordinated manner, and build upon each other.

This document covers a variety of topics (and indeed it includes some diverging views). It will be worthwhile at the outset to explain briefly why these matters have been addressed.

Research Designs

Research designs have a central role in archeology today, and in cultural resource management. Managers often do not realize this, and conclude erroneously that historic preservation is conducted in an intellectual vacuum. For this reason we discuss briefly the role of research designs in the discipline.

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[1]Paper prepared at the Forest Service Cultural Resources Research Symposium [Grand Canyon, May 2 - 6, 1988].

[2]Evan DeBloois is Chief Archeologist, USDA Forest Service, Washington, DC.

[3]Shereen Lerner is the Arizona State Historic Preservation Officer, Phoenix, AZ.

[4]Linda Lux is a historian with the USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

[5]John Schelberg is an archeologist with the Albuquerque District, U.S. Army Corps of Engineers, Albuquerque, NM.

[6]Joseph Tainter is an archeologist with the USDA Forest Service, Cibola National Forest, Albuquerque, NM.

[7]David Wilcox is Assistant Curator at the Museum of Northern Arizona and an adjunct faculty member with the Department of Anthropology, Northern Arizona University, Flagstaff, AZ.

Archeological Goals

Archeology in recent decades has gone through a period of very rapid change in goals and assumptions. These changes in the framework of the science will of course influence management priorities. It is important that non-specialist managers understand both these changes and the current goals of archeology.

Goals of State Planning

An essential matter to discuss is the nature and goals of state historic preservation planning. This level of planning, as noted, is intended to guide statewide efforts.

Examples of Planning

In some places, Federal agencies and State Historic Preservation Offices are already developing systems of the kind we have in mind. Some examples are described in the sections titled "Comprehensive Planning in California" and "The Southwest Division, Corps of Engineers, Cultural Resources Overview."

Integrating Academic and Management Archeology

In the experience of many specialists there is often a conflict between the needs of managers and the standards of scientific research. A section of the paper is devoted to discussing the needs and expectations of academic archeologists. This is a matter about which managers need to be aware.

Data Base Management

One item that emerged in the course of our discussions as highly important is data base management. Many questions of both management and research would be easier to answer if we possessed electronic data bases that contained archeological, environmental, and managerial information. Such data bases will be most applicable and cost-effective if they are developed by, and useful for, several agencies.

We conclude with a discussion of considerations in designing a program of integrated research, and with a recommendation for work to pursue first.

RESEARCH DESIGNS

One major component of archeological research conducted today, especially in the context of "contract archeology," is the use of research designs. Research designs provide a structure or basis from which avenues of inquiry may be sought. Research designs define goals and objectives, and the approaches or methodologies to be used to achieve them. One of the advantages of a research design is that it may be used as a tool to define the scope of a project. Research designs, however, must also be dynamic, to allow for refinement of research questions and enhancement of approaches as information is gathered. The integration of research designs with management archeology is critical to identifying key research issues, the data necessary to address those issues, and agency/management objectives.

ARCHEOLOGICAL GOALS

One of the more common misconceptions of agency managers is that archeology is primarily a descriptive discipline in which data are gathered ad infinitum. This misconception arises as a result of the differing assumptions, objectives, and goals held by managers and archeologists. One manager was recently heard to complain that all archeologists do is survey and record sites, plot them on maps, file the information, and then tell the manager what he or she can and cannot do in an area. This complaint clearly expresses frustration and a lack of understanding by the manager of the goals of archeology. This lack of understanding is a result of the agencies' need to focus most of their work on compliance actions, thereby preventing the archeologists from taking the data collected to the next step - beyond management needs and into research aimed at understanding human behavior. Because of the need to meet the mission of an agency, archeology in an agency is often descriptive, only venturing into interpretation when avoidance of sites is not feasible and actual data collection and analysis may occur.

Archeologists seek not only to collect data but to interpret them as well. Over the years there have been numerous changes in the goals of archeology, both of a theoretical and a methodological nature. At the data collection level, archeology has evolved from collecting primarily decorated ceramics, projectile points, and formal tools, to collecting all types of artifactual material as well as botanical and faunal remains. The recording and study of archeological sites has shifted from an emphasis on large sites with visible structures, to the point where even isolated artifacts are recorded as evidence of human activity. Although isolated finds are not usually studied beyond initial recording, small sites with surface scatters of artifacts are now routinely examined whereas just a few years ago they were typically overlooked. This new penchant to look at smaller data sets does not suggest that the large sites have been exhausted or are fully understood, and that only small ones are left to study. It suggests rather that the big sites provide only one view of a larger behavioral system. For example, to study only Phoenix without understanding Ajo or St. Johns would provide a biased view of life in Arizona, leaving out many details of the social, economic, and political systems of the state.

Archeological goals therefore have changed from the description of cultural remains to an effort to understand human behavioral systems. Not only have the types of data gathered and the types of sites recorded changed, but also the research questions that are asked. In the Southwest we seem to go in cycles, changing our focus of research every decade or so. Chronology, water-control devices (canals), sociopolitical systems, exchange, and community patterns are all issues examined in the past ten years. Some of these issues are studied on a fairly regular basis, others more sporadically. New issues such as the identification of temporary structures (field houses) in the Salt River Valley are being explored. Change in research issues does not mean a change in priorities but merely a shift in focus. This is often a result of the discovery of new information. A key factor is that while not all research questions can be answered, neither should posing such questions be limited or restricted to management needs. A compromise between management and research needs is necessary to allow for flexibility, thus permitting archeological goals to change as new information is gathered and incorporated into existing data bases.

GOALS OF STATE PLANNING

Each state is required, by law (National Historic Preservation Act, 1966, as amended), to implement a planning process that culminates in the development of a State Historic Preservation Plan. While the plans themselves are unique to each state, they are guided by a common bond and they tend to be resource-based. By necessity, the planning documents should identify the status of current knowledge of cultural resources in each state. As part of such a structure, no plan should be seen as a finalized document. The plans are dynamic and changing tools that must constantly integrate new information and research objectives.

The plans themselves, however structured, should accomplish several goals. These goals include:

1. identify data gaps;

2. identify research needs;

3. define historic and prehistoric research contexts;

4. guide research and data collection;

5. integrate different data sets;

6. identify research priorities, especially in areas under development pressures;

7. integrate with agency management plans;

8. centralize data;

9. reduce redundancy; and

10. enhance creativity of research.

These goals overlap to a great extent and in the following discussion are combined to elucidate their interrelationship.

Data Gaps/Data Collection

These terms correspond to the identification of areas in which very little archeological work has been conducted. This identification does not preclude continuing to work in areas where a great deal is known, but it is worthwhile to define areas where greater information is needed. Information on data gaps can be extremely useful in establishing survey priorities, especially if combined with other factors such as development pressures. Two examples of areas under such pressures, yet with different amounts of information, illustrate this point.

A great deal of work has been accomplished in the Tucson Basin area, which allows archeologists to work with developers on advance planning for the treatment of archeological resources. Compromises on overall research goals and the extent of archeological research to be conducted may be achieved due to the amount known about the area. Greater emphasis can be placed on key research issues that have not yet been explored in detail, while other, more general research questions which have been examined extensively may be reviewed in less detail.

In contrast, much less work has been done along the Colorado River and to the east - areas considered part of the Western Desert of Arizona. The work that has been accomplished has been sporadic, and provides primarily survey information. Few sites have been excavated. Although overviews of the area have recently been completed (Stone 1986, 1987), in many ways these highlight the gaps in our knowledge of the prehistory of the region rather than fill in the blanks. The modern towns bordering the Colorado River are under immense development pressures and are expanding rapidly. Archeological work in these areas must still focus on broad research topics rather than on more specific ones. A comprehensive, synthetic study of the data collected to date, even though the majority is surficial information, is necessary to begin to understand some of the area's more ephemeral features (such as rock piles, rock rings, and trails).

Guide Research, Define Research Needs

Research objectives can be identified in planning. In the Tucson Basin area, for example, there is still a great deal to be learned about the latest period of Hohokam occupation, while the middle (Rincon) periods have been investigated to a much greater extent. In contrast, in the Western Desert area we are looking at a hunting and gathering society that left behind ill-defined

surface features. Not only do we need to learn more about the function of these features, but also how they relate to one another. For example, a GIS computer system which plots all known prehistoric trails or rock piles, overlain with topographic and vegetation data, could provide valuable information on population movements and subsistence of the prehistoric inhabitants. This does not mean that the Western Desert is a higher priority for research than the Tucson Basin, only that the current state of knowledge combined with management issues such as developmental pressures must be taken into account.

Data Centralization and Integration

One of the key ingredients of being able to identify data gaps and research needs is to centralize the data already collected, and to integrate different data sets. It is critical that a sound data base management system be developed in which data from all over the state and collected by different agencies can be stored. This should not only include artifactual and site data but also ethnobotanical, faunal, petrographic, and other data sets. Too often the specialized data collected are not integrated with other archeological data, thereby providing an incomplete picture of prehistory.

Management Needs

Management needs must also be taken into consideration. The State Plan should assist agencies in the management of cultural resources by identifying such matters as where more work is needed, and where a great deal is already known. This will prevent redundancy in data collection, enhance creativity of research, and address the overall research needs of the agency. For example, the plan could assist an agency in developing predictive models that draw together not only topographic features and known site data, but also research needs coupled with management goals.

In summary, state historic preservation planning should be an evolving process in which many factors come into play. By its very nature as a document for use on a statewide rather than regional basis, the State Plan overcomes the territorial or restrictive view which is often inherent in agencies' land-ownership patterns. State planning should be comprehensive, including not only descriptive information about the resources, but also assisting in identifying research that is needed. A plan is not meant to be an exclusionary document; that is, research not identified in the planning process can and should still be done. A plan sets <u>priorities</u> for research. These priorities change over time as our knowledge is enhanced. The document, therefore, is dynamic, assisting both researchers and managers in achieving their differing, yet overlapping, objectives.

COMPREHENSIVE PLANNING IN CALIFORNIA

Comprehensive planning as it is being applied in California provides one example of integrated research strategies, and of the factors that lead to their successful implementation. In 1986 a landmark meeting was held which included representatives from state and Federal land-managing agencies as well as private research organizations. This group of cultural resource professionals came to the meeting in agreement on two important points:

1. there is a need for the various agencies in California to pool resources in order to provide regional focus on specific research questions and management problems; and

2. interagency cooperation and support were essential for solving these problems.

Agreement on these two basic premises is fundamental to the success of any comprehensive historic preservation program, whether it is management- or research-oriented.

The Pacific Southwest Region of the Forest Service, as one of the largest land-managing agencies in California, joined this effort to explore opportunities for developing a more consistent, efficient approach to cultural resource management, and particularly to develop strategies for the programmatic identification, evaluation, and treatment of specific cultural properties (Lux, this volume). While the interagency team was initially concerned with properties that were threatened with destruction or other adverse impacts from land-disturbing activities, over time the emphasis shifted to developing a comprehensive plan for directing and systematizing the management of cultural resources. Each of the participating agencies was faced with similar problems, and was interested in cooperating to solve these problems.[8]

This effort was initiated in response to several concerns:

1. the need to establish professional agreement on priorities for the preservation of cultural resources;

2. the need and desire to consider various complementary approaches to state historic preservation planning that would meet short- and long-term goals;

3. the continued and intensifying pressures exerted by development interests and land-disturbing activities; and

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[8] Jackson, Robert. 1986. Meeting notes: a consideration of programmatic approaches to the management of archeological resources. Meeting held at the California Office of Historic Preservation, April 15, 1986, Sacramento.

4. the difficulties state and federal agencies were facing in complying with mandated historic preservation laws for their undertakings, and the problems faced in reviewing these projects.[9]

Archeologists and historic preservationists were being challenged to make major organizational and procedural changes in the conduct of cultural resource management. California, with its natural, cultural, economic, and political diversity, has presented complex problems with regard to establishing practical and functional planning throughout the state. An approach was needed which would increase predictability and efficiency in project planning and development, reduce inconsistency and delay in the review and compliance process, and simultaneously provide for the systematic collection of comparative research data and a unified, consistent approach to making historic preservation decisions.

It was agreed that many kinds of cultural resource properties offered a possibility of systematic treatment, and could be considered as representing an historic theme. These property types range from sparse lithic scatters to complex railroad logging systems, from tin can deposits to historic structures. After consensus was reached on the property types most appropriate for the initial effort, each agency took the responsibility for designing and implementing certain thematic comprehensive plans which would serve as models for future efforts. Other thematic designs that were of equal concern to several agencies are being developed by teams representing those agencies.

There are several benefits to this approach:

1. By agreeing that certain classes of properties can be evaluated and managed in a programmatic way, the Section 106 compliance process of the National Historic Preservation Act is facilitated. Rather than the fragmented, inconsistent approach that had been used, the thematic approach prioritizes where historic preservation efforts will be focused.

2. Standardized and consistent guidelines for evaluation and management decisions allow cultural resources managers to perform their jobs more efficiently.

3. Increasing information about priorities will help land managers incorporate historic preservation goals into the agency's broader mission.

4. Researchers will have access to more consistent, reliable data for study.

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[9] Gualtieri, Kathyrn. 1986. Personal correspondence. Department of Parks and Recreation, State of California. On file, Regional Office, USDA Forest Service, Pacific Southwest Region, San Francisco, California.

How, then, does this apply to an initiative for cultural resources research in the Forest Service? What lessons are to be learned? Historic resources do not usually correspond to today's political organizations. State Historic Preservation Offices review projects that affect cultural resources, and overall standards and guidelines for the profession are defined by the Secretary of the Interior. Cultural resources management is a multidisciplinary endeavor, requiring the expertise of archeologists, historians, and anthropologists. Cultural resources are, furthermore, only one of the resources that need to be considered in the agency's land management planning. Cultural resource management cannot function in administrative isolation.

In order for researchers successfully to develop methods and strategies for forest managers to implement on the ground, they will need to do so in a climate of cooperation with each of the various agencies, and involving the appropriate disciplines. For new methods to be widely accepted and supported within the Forest Service and by the professional and scientific community, a common agreement on priority problems will need to be the basis for work. A truly integrated approach is the only one that will succeed. Risks will be taken in the process and we will all have to agree in advance that the benefits of new knowledge make it worthwhile.

THE SOUTHWEST DIVISION, CORPS OF ENGINEERS, CULTURAL RESOURCES OVERVIEW

The Southwest Division, U.S. Army Corps of Engineers (COE), extends from the New Mexico/Arizona border into Arkansas and Louisiana, and covers approximately 25 percent of the continental United States. This vast expanse of territory includes a diversity of ecosystems, as well as archeologically-defined cultural systems and historically-recorded groups. The intensity of archeological investigations, the availability of reports, and the frequent lack of empirical data across the Southwest Division (SWD) run the full range from nonexistent to excellent. Over 65,000 sites have been entered into the New Mexico state site files and over 20,000 have been recorded in Arkansas. The numbers of sites, the variability of recorded data, and the range in quality (or even the existence) of syntheses prohibit meaningful understanding of prehistoric and historic adaptive strategies beyond any scale but local. Regional and panregional considerations can currently be addressed in only a cursory fashion.

It might be assumed that the archeological reports for Corps projects would not fit into this characterization but unfortunately most, if not all, of these criticisms are applicable to work done for the agency. COE projects reflect the growth of cultural resources management from the initial National Park Service-sponsored and

-funded work to the Corps' own programs. The reports vary in utility, data, and the presence or absence of meaningful research questions. Usually the only attempt at synthesis is a chronicle of culture history, slavishly repeated from report to report. Some reports do not even discuss prior investigations in a project area. It is rare for one firm to conduct all of the work on a project since funding extends over a period of years. The net result is a series of locality-specific reports united only by the fact that they present the work conducted at one project. In the case of the Corps, these projects are usually bands of territory extending three to six meters around a reservoir. The absence of syntheses and computerized data bases, combined with incomplete or disparate site records and reliance on individual memories for the histories of project-specific undertakings, lead to uneven resource management and an inability to deal effectively with such emergency situations as high spring runoff.

While the SWD owns an insignificant amount of land, it does have permitting requirements along major rivers, streams, and coast lines. On the one hand, this requirement does not dramatically increase the number of acres when compared to the overall size of the SWD. Yet on the other hand, SWD archeologists need to be aware of the full range of cultural and environmental variability within a district. Given the restricted area of responsibility (that is, reservoirs and areas close to rivers), it is essential to understand past cultural relationships, intensity of prior archeological undertakings, and relevant research issues in order to establish a context in which to evaluate an archeological site or sites. In view of the factors discussed above, this is extremely difficult, if not occasionally impossible, and a site must be evaluated with respect to itself and to generalized research issues.

The modern population within the SWD area is growing at an increasing rate. Undeveloped land and areas of difficult access are disappearing. The availability of comparatively small quantities of money for CRM requires that decisions be made concerning not only which sites are tested or excavated, but also the intensity of the work undertaken and the kinds of research questions which could or perhaps should be emphasized.

In an attempt to compile existing data and make it more readily available, and to inform SWD's executive-level management about archeological issues and requirements, several kinds of projects were considered. The one chosen evolved from a single, relatively simple, division-wide overview into the project that will be summarized below. This evolution resulted from the conditions discussed above - that is, the very large area, the disparate availability of information, the archeological diversity and, in the absence of syntheses, the need to integrate numerous scholars with a diversity of interests and backgrounds.

From the outset, the structure and integration of the project was of some concern. This was, in part, a reflection of the internal organization of the SWD. It consists of five districts covering all or parts of six states. Several districts include portions of two or three states. This organization presented the opportunity to structure the overviews to reflect the major geophysical settings, and not only to ignore modern political boundaries of states but also those of the COE's five districts. Thus the overviews were structured by the archeological and geophysical units which are commonly utilized by archeologists when considering prehistoric and historic adaptations.

In response to a request for proposals prepared by SWD chief archeologist Larry Banks, the Arkansas Archeological Survey was awarded a contract for the project. In order to prepare the required material effectively, subcontracts were awarded to institutions working in or familiar with the subregions within the Division. These included the Desert Research Institute, the Oklahoma Archeological Survey, the Texas Archeological Research Laboratory, and researchers from at least eight universities and the Smithsonian Institution.

The primary goal of the project was to produce five major documents. The first was a paleoenvironmental volume covering the entire SWD. To the extent possible, the prehistoric and early historic climatic and ecosystemic characteristics were to be discussed in as detailed a manner as the available literature permitted. Recommendations for future study and analyses were to be made.

Five overviews were written, corresponding to the subdivisions established for the project, of the prehistoric and historic archeology. An important concern was to integrate the overviews so that a level of comparability would be maintained across the Division. The diversity of backgrounds and research interests of over twenty major authors necessitated an integrative framework which would, if not achieve a synthesis, at least provide for a common treatment of the material. The overviews were structured around the concept of adaptation type (Fitzhugh 1975). Several authors expressed reservations but nevertheless complied with the structure. The generalized conceptual framework of adaptation type, which characterizes relationships among technology, adaptation, and environment, permitted regional summaries not weighed down in local issues of interpretation. While this results in a product of less utility to local specialists, it provides a compressed introduction to many parts of the country. This approach does not provide for detailed analyses or processual studies, but that was not the intent.

One primary topic, the bioarcheological knowledge within each overview area, was discussed by a specialist. Usually several chapters were devoted to the topic, including an attempt to determine such factual information as the number

of burials recovered, the number retained, their location, the number analyzed, and the kinds of analyses conducted on them. It would appear that smaller percentages were analyzed than one would assume, that the majority of the analyses are simple measurements, and that systematic investigations of paleopathologies, diseases, and genetic characteristics are rare.

In order to facilitate discussion and comparison, each prehistoric and historic adaptive type was summarized by eleven categories of information, including date range, environmental and cultural contexts, site types and their distributions, bioarcheology, sensitive areas of high site probability, data gaps, and critical research questions. Compilation of the material in this overview fashion permits a critical evaluation and some degree of quantification of what has been done and where. Fewer rigorous analyses have been undertaken than would be generally assumed.

A computerized, annotated, and fully cross-indexed bibliography of over 10,000 reports is being prepared. The indexing includes state, county, geographic coordinates, and attributes commonly recorded by archeologists such as site type, cultural affinity, and features. It is intended that this data base will be made available nationwide, although funding is not presently sufficient for this.

A computer file of site attributes was created. It is compatible with the Geographic Resources Analysis Support System (GRASS). The level of detail varies from site-specific location for over 20,000 sites in Arkansas (a project initiated by the Arkansas Archeological Survey for the National Park Service prior to involvement with the COE) to summary data by county for other areas. Site locations can be displayed by state or by county, or within specified geographical coordinates. Panregional categories of data can be displayed as color densities on accurate maps for the entire division or for any subdivision of interest. A set of variables (e.g., habitation sites with burials contrasted with centers of modern high population concentrations) can be displayed as color densities within each county in the SWD in a weighted fashion, so that counties in, say, New Mexico and Arkansas, can be compared or contrasted by color and density. The GRASS program is extremely powerful, is currently being upgraded, and - since it was developed with public funds - is free. It does require fairly sophisticated computer equipment.

Finally a short, executive-level summary will be prepared which discusses major geographical areas of the most immediate concern, major data gaps, research questions, and the current level of understanding of past adaptive strategies. It should be mentioned that this was the original and only document thought to be necessary when the project was first discussed.

It is important to point out what these documents are not. They are not COE reservoir-specific compilations and do not alleviate COE archeologists from the need to create reservoir- and project-specific research strategies for future work. Future research strategies can, however, be designed to address some of the data gaps and critical issues identified in the overviews.

It will be necessary to update the information as often as possible. While some have suggested five-year updates, a cycle with that periodicity would fail to take advantage of the flexibility of the system. It may be that certain kinds of information should be reviewed on a panregional basis every few years but newly acquired, essentially local data, must be entered quickly.

Interagency Cooperation

The SWD archeological overview provides an example of an integrated approach to a vast area and a large, complex body of data. Five major institutions and over twenty principal authors were involved. In an era of expanding land disturbance and restricted funding for cultural resources, integration of another sort must be attempted. Archeology is burdened by two dichotomies which are an amalgam of myth, reality, and perception. These are the separation of research from management and of academic researchers from cultural resource managers. Neither rift can ever be fully closed, but the perceived gaps must be narrowed through cooperation and communication. As long as management and research are played against each other, the cultural resources will suffer. Given the diversity and intensity of day-to-day impacts, the costs associated with archeological survey and mitigation, and the diversity of specialized analyses necessary for accurate reconstructions of past behavior, it is incumbent upon agencies and institutions to cooperate in conducting management and research projects whenever possible. Many agencies have land adjacent to and often within the boundaries of other agencies; however, projects are frequently conducted as if in a vacuum. Partially this is a problem of communication but it is also the result of differing agency missions.

All agencies are interested in doing more with less. No matter how large an archeological project, a number of fixed costs are always attendant, including those associated with administration and getting started. A greater portion of a small project budget goes to non-archeological tasks than is the case on a larger project. Cooperation, leading to economies of scale, would benefit the resource, the research, and the agencies involved.

Clearly certain projects are more amenable to cooperative efforts than others. For surveys along adjoining land jurisdictions, it would not be difficult to justify joint efforts. Specialized analyses leading to a determination of the utility of an approach or technique and/or the

building of a data base would also benefit from cooperation. Recently the Albuquerque District of the Corps of Engineers has been involved in archeological projects which would have been ideal for cooperative efforts. These included: (a) confirming obsidian hydration rates and the intensive dating of over 700 obsidian artifacts from 55 sites located at Abiquiu Reservoir immediately adjacent to Forest Service land in New Mexico; (b) an attempt to determine the utility and accuracy of thermoluminescence dating of burned caliche; (c) geomorphological reconstruction of the post-Pleistocene sequence on Air Force land 20 miles west of the Clovis sites at Blackwater Draw; and (d) an analysis of temporal characteristics of debitage from lithic scatters. While the overall success of these undertakings varied, their potential utility far exceeds the research needs of only the Corps. Additional funding for these kinds of projects would permit the incorporation of larger data sets and the delineation of associated problems, and would eventually produce more accurate bodies of data.

Interagency cooperation should be initiated on several levels. One of the easiest is for an agency that is well-staffed with archeologists to approach another with few archeologists, and offer expertise in survey, excavation, and research. The Albuquerque District has worked for the Air Force and the Department of Energy under such a program. Those agencies provided the funds and the Albuquerque District managed the undertakings.

From the perspective of an agency archeologist, the most important level at which to institute interagency cooperation would be Washington or a region, since district management is responsive to directives from above. On the other hand it is at these higher levels that funding and turf battles can be the most intense. At the district level cooperation should be easier to achieve but little funding is likely to be available.

The creation of a new program in the Forest Service's Rocky Mountain Research Station provides an opportunity to initiate a discussion of increasing cooperation at all levels of management. Agencies are always interested in long term, cost-effective approaches which could relieve some of the burden on a typically overworked staff. Creative approaches for providing money need to be considered, since annual budget requests are initiated two years in advance and are frequently pared down prior to the actual year of availability. If two agencies are planning jointly to fund a project, some mechanism must be developed so that both receive an appropriation that will allow each to fulfill the agreement.

INTEGRATING ACADEMIC AND MANAGEMENT ARCHEOLOGY

Forest managers - and other land managers - play a unique, powerful role in archeology because they control resources. Forest archeologists and Forest managers can make decisions that will greatly affect the future of American archeology. They can decide to protect some sites but not others. They can allow some archeologists to study Forest resources, but direct others to go elsewhere. And they can encourage certain lines of research while discouraging others. This is an enormous responsibility, yet it is one that is little understood.

One aspect of this problem is that state and Federal planning have not taken into account the diversity of approaches in the field. The struggles among proponents of different philosophical positions cannot be reduced to homogeneous historic themes of the sort that some planners advocate. It is therefore quite dangerous to use such plans to decide which research orientations should be supported and which should not. As compilations of data and summaries of research needs, such plans are quite useful. As an attempt to reduce planning and research decisions to a mechanical computation they are problematical.

Some archeologists, for example, are concerned with explaining why social systems develop and collapse. Others are preoccupied with learning what factors determine social structure and social change. Still others are concerned with understanding what people ate and what factors influenced how they made their tools and their art. No doubt these orientations overlap in many ways, but in the end they defy simple synthesis of the kind sometimes seen in plans.

In archeology, as in every science, knowledge increases and interpretations change over time. This is noticeable in such fields as physics and astronomy, but it is equally true of the social sciences. The Forest Service's research branch can - and should - play an important role in keeping agency archeologists abreast of the state of archeology, and of its ongoing evolution.

A program of integrated research could do much to bridge the chasm between agency and academic archeologists. There are two areas in which this might be accomplished. Firstly, the agency should encourage its archeologists to publicize their views, interpretations, and management priorities. They would subject themselves in this way to the standard controls of peer review and criticism. The Forest Service Research Stations could appropriately provide the forum that would make this possible. Peer review should be a central component of any cultural resources research program the agency might undertake.

Secondly, the research branch should develop a program of technology transfer, so that new developments in archeology can be disseminated to the management branch. One way to achieve this is through a "visiting scholars" program. In this program, management archeologists would be temporarily reassigned to a Research Station in order to participate in ongoing Station research, or to pursue limited research projects of their own devising. The overriding purpose of these temporary assignments would be to transfer new developments in knowledge and technology to management

archeologists. In returning to their permanent positions these individuals would then be able to apply the new knowledge and technology in better management of Forest resources.

DATA BASE MANAGEMENT

The primary underpinning of the decision-making system in any organization is the accuracy of its information base and its relative accessibility to the decision-maker. For the last decade and a half, the Forest Service cultural resource management program has been producing data about cultural properties on NFS lands as a result of thousands of surveys conducted for a wide variety of reasons (figs. 1 and 2). However, as pointed out in a 1986 CRM program review, rarely are these data utilized either in designing cultural resource management strategies or in directly supporting management decisions. The recommendation of that review was:

> Generally, Forests and Regions need to analyze the results of the inventory efforts that have been accomplished over the past decade. Both project and non-project inventory information needs to be used, rather than just filed, in order to direct future integrated resource management, and to assist in the evaluation and enhancement of cultural properties.[10]

One of the reasons for the failure to utilize these data is their relative inaccessibility. The computerization of these data is uneven across the National Forest System; some Regions have automated data bases for cultural properties, some have them for projects, some have them for both properties and projects, and some have neither. The same is true of the Forest Supervisors' offices. Even in those instances where automated systems exist, they do not appear to be used consistently and reliably in the decision-making process, particularly outside of the cultural resource management program.

Although the reasons for this failure can be understood in terms of staff and time limitations, it is more difficult to understand why the necessary resources have not been made available. Clearly it is not due to absence of the technology to develop such a decision-support system. The explosion of technological advances in the last decade has produced many exciting new ways of presenting cultural resource data that can directly support decision-making. Powerful and inexpensive portable and desktop microcomputers have been developed that permit rapid retrieval and display of information from a data base that would facilitate the decision-making process for both the specialist and the manager.

[10] USDA Forest Service. 1986. Cultural resource management, program review, p. 9. On file, USDA Forest Service, Washington, DC.

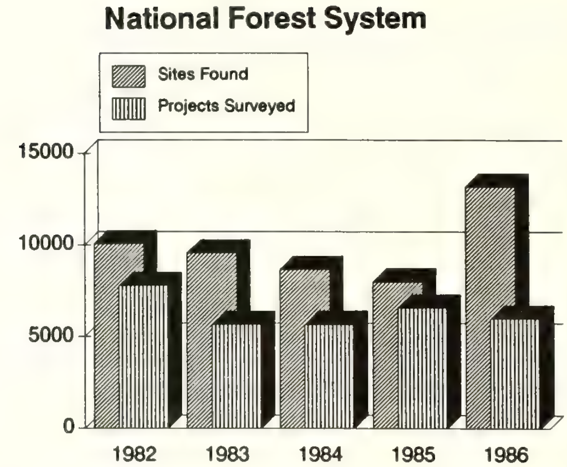

Figure 1.--Projects surveyed and sites found, USDA Forest Service, National Forest System, 1982-1986. Data on file, USDA Forest Service, Recreation Staff Unit, Washington, DC.

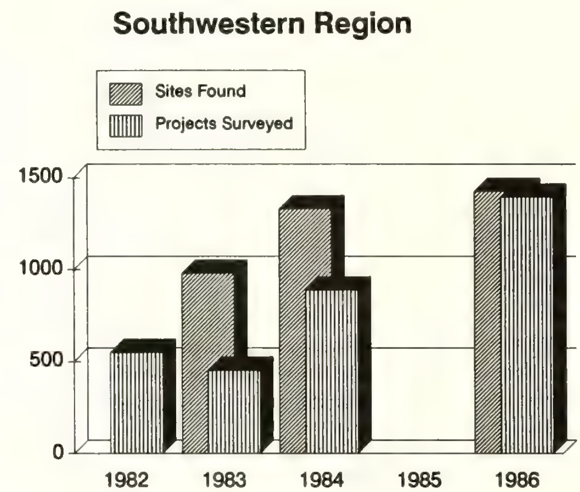

Figure 2.--Projects surveyed and sites found, USDA Forest Service, Southwestern Region, 1982-1986. (Data missing for 1985). Data on file, USDA Forest Service, Recreation Staff Unit, Washington, DC.

The first Forest Service CRM Program Review in 1976 identified the development and implementation of a CRM data base as a top priority. A task force was formed to address this issue; it recommended that each of the nine Regions develop and implement automated data base systems. After twelve years, relatively little has been done to meet this objective outside of Regions 3 and 4. Even in those Regions, major problems remain to be solved before the cultural resource data base becomes a useful tool in supporting the decision-making process.

It is not that management has not recognized the need for, and the advantages of, automated systems; many individual efforts have been made to bring some order and usefulness into data bases.

A number of Forests have developed automated systems for their data, several Regions have struggled with data base development, and the Washington Office has organized numerous meetings and task forces to discuss the problem. States have developed data bases, the National Park Service is working on the development of national data bases for both properties and projects, and yet management continues to complain about the lack of decision-support information. The major barrier to achieving success in the development of an automated system for cultural resource information appears to be the absence of a large enough effort to accomplish the task. An effort by the Research Branch could accomplish what NFS has been unable to do because of the dispersion of its CRM resources across the system and the consequent difficulty it has had in assembling sufficient expertise and funding to define, design, and implement a CRM information management system.

It is clear from the discussions at this symposium that an underlying need of all the research topics is data bases that are accessible and that contain useful and reliable information on cultural resources. An immense amount of information has been collected over the past fifteen years that could provide a major tool in the management of cultural resources. This data base or data bases would provide the foundation for a myriad of research topics that would add to our understanding of the resource and improve management efficiency and effectiveness.

Such a data base in readily-accessible form would also permit better cooperation between Federal and state agencies in the management of cultural resources on a broad scale. Interagency cooperation in the use of data bases will provide a much-enhanced decision-support system. It will contain information that is better than that derived only from NFS land. This is an area that will greatly reward an integrated effort.

Until we can control and utilize the information that has been collected about cultural resources on the lands administered by the Forest Service, and on the lands administered by other federal and state agencies, we can take but small and tentative steps toward resolving the issues facing the management of the Nation's cultural resources.

An Example of Integrated Data Base Planning

One of the most promising technological developments in the past few years is the Geographical Information System (GIS). These computer programs offer ideal management decision-support systems, for they allow the retrieval and display of many kinds of information in a wide range of combinations (see Calamia, this volume). The Intermountain Region of the Forest Service is cooperating with other State and Federal agencies in Utah in a project to include the cultural resource information from all sites in San Juan County, southeastern Utah, in a GIS system that can be utilized by any and all of the participating parties in both the management of, and research on, the prehistoric resources of the county. Over 15,000 sites have been identified by the Forest Service, the Bureau of Land Management, the National Park Service, the Navajo Tribe, and the State Archeologist's Office. Information on roads and trails, elevation, soils, vegetation, streams, site surveys, and site characteristics and conditions are being entered into the data base. Once completed, a wide variety of questions can be addressed by these data. The Forest Service, among other agencies, is interested in developing models of site theft and vandalism, using such variables as vicinity to roads, visibility, site characteristics, and ruggedness of terrain to try to identify those sites most at risk from illegal activities. Once completed, this GIS data base can be used to address an almost endless series of questions of importance to both resource managers and researchers.

PROGRAM STRUCTURE

The elements of a successful program of integrated research include the right structure, the right people, sufficient funding, and agency support. Only the first item can be dealt with at this point.

To begin with, such a program should be explicitly linked to state historic preservation planning. A Forest Service program of integrated research can provide one means of developing and implementing a State Plan. The linkages among Forest Service management and research, state planning, and the management goals of other agencies should be specified in a Programmatic Memorandum of Agreement. This memorandum would specify, at a minimum, the following:

1. the program to be accomplished;

2. the roles and responsibilities of each party.

3. the mechanism whereby research designs will be developed; and

4. the means of implementation.

From the Forest Service's perspective this effort should be linked to the agency's land management planning process. On each Forest the Land Management Plan will specify, among other things, what the management needs are for cultural resources, and what research is needed to address those needs. Management issues can be addressed in such a plan at a finer level than is possible in a State Historic Preservation Plan. Yet Forest- and state-level planning should not proceed in isolation. Each should build upon the other. A program of integrated research can provide the link between these levels in such areas as data base management, designing joint research, technology transfer, identifying information needs, and coordinating results.

Developing a program structure will involve making decisions in the following areas:

Staffing. The options here are to base the program in the Forest Service research branch, or to do all or much of the work by contract. The former alternative is preferred. The requirements of this work are, firstly, that it be done by an archeologist who is knowledgeable about the Forest Service, and secondly, that it be done by someone who can devote undivided attention to it. These requirements are more likely to be met in a Forest Service employee than in a contracting institution. The reasoning behind these requirements has been detailed elsewhere (Tainter, this volume). To remain timely and useful, integrated research designs must be constantly evaluated and revised. This requires that the work be done by a specific individual who has no assignment of higher priority.

Development. Building integrated research designs is a political process. The goal is to engineer a consensus among archeologists about priorities in research and management. This can be done in several ways. Research designs can be developed by a single archeologist - a research czar - and imposed on the profession. At the opposite extreme the work can be done through a "town meeting" format, in which research is designed by anyone with an opinion to offer. Neither of these approaches is desirable. The research-czar approach will inevitably engender resentment among the specialists on whom the research design is imposed. The town-meeting format is a prescription for chaos, and for the selection of least-common-denominator topics.

It has been argued elsewhere that under the political structure of archeology - which is a discipline characterized by low theoretical consensus and few leaders - the best approach to designing research is by a designated group of the leaders of the field (Tainter n.d.). Accordingly, it is recommended that the following steps be taken to develop research designs.

1. Divide the Southwest into geographical subunits appropriate to research and management.

2. In each geographical subarea, organize a committee of the leading scholars to develop integrated research designs.

3. Once these scholars have prepared draft research designs, convene an open symposium of all interested persons to debate the merits of the proposed designs.

4. Based on the outcome of the symposium, revise the proposed designs, if necessary. Proceed to implement the final designs to guide survey, excavation, data base management, and preservation decisions.

Scheduling. Management through integrated research must be sensitive to the dynamic nature of archeological science. Nothing could be worse than the image of a fossilized government agency making management decisions by outdated criteria. Two steps must be taken to avoid this: (1) begin such a program with the realization that it must be continuously evaluated and revised, and that this will require continuous funding; and (2) build an automatic termination date into each research design. The latter point is critical. After a research design has been in effect for, say, 24 months, the project archeologist should begin to evaluate its results and usefulness, and whether it is still current in archeology. After 36 months the research design should automatically terminate, as should all management decision-making criteria based on it. At this point one of three steps should be taken. As appropriate, the research design can be reissued as is; or it can be modified and reissued; or if it is obsolete, it should be discarded altogether. It would be irresponsible to develop integrated research designs without provision for continuous appraisal and automatic termination.

RECOMMENDATION

A great many topics have been touched on in this paper. We have outlined the need for integrated research designs, and the advantages they confer. We have also recommended several steps that the research branch of the Forest Service could take to gain these advantages. We see three major actions that the research branch could undertake to facilitate integrated research.

1. Serve as the coordinating agency for a program of integrated research that incorporates Federal agencies, State Historic Preservation Offices, and non-government archeologists.

2. Support a program to transfer technology to the management branch.

3. Develop a cultural resources decision-support system (a data base) that will allow managers and researchers alike to access cultural resources information readily.

While all of these are important tasks that the research branch should undertake at some point, the last item seems to be the most urgent. For reasons discussed above, a cultural resources data base to support decision-making and research is one of the agency's most critical needs. It could provide management with greater use of existing data, and would be the first step toward an integrated research program. The development of a GIS data base system is accordingly the task that we recommend be undertaken first.

CONCLUDING REMARK

As outlined in these pages, a program of integrated research presents a challenge to a Federal agency that faces a convergence of increasing responsibilities and declining funds, and that must make irrevocable preservation decisions. Yet in that challenge lies an opportunity to develop an exemplary program of cultural resources management, and to make an investment that will yield dividends for decades to come.

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☆ U.S. GOVERNMENT PRINTING OFFICE:1988-576-355/85202

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

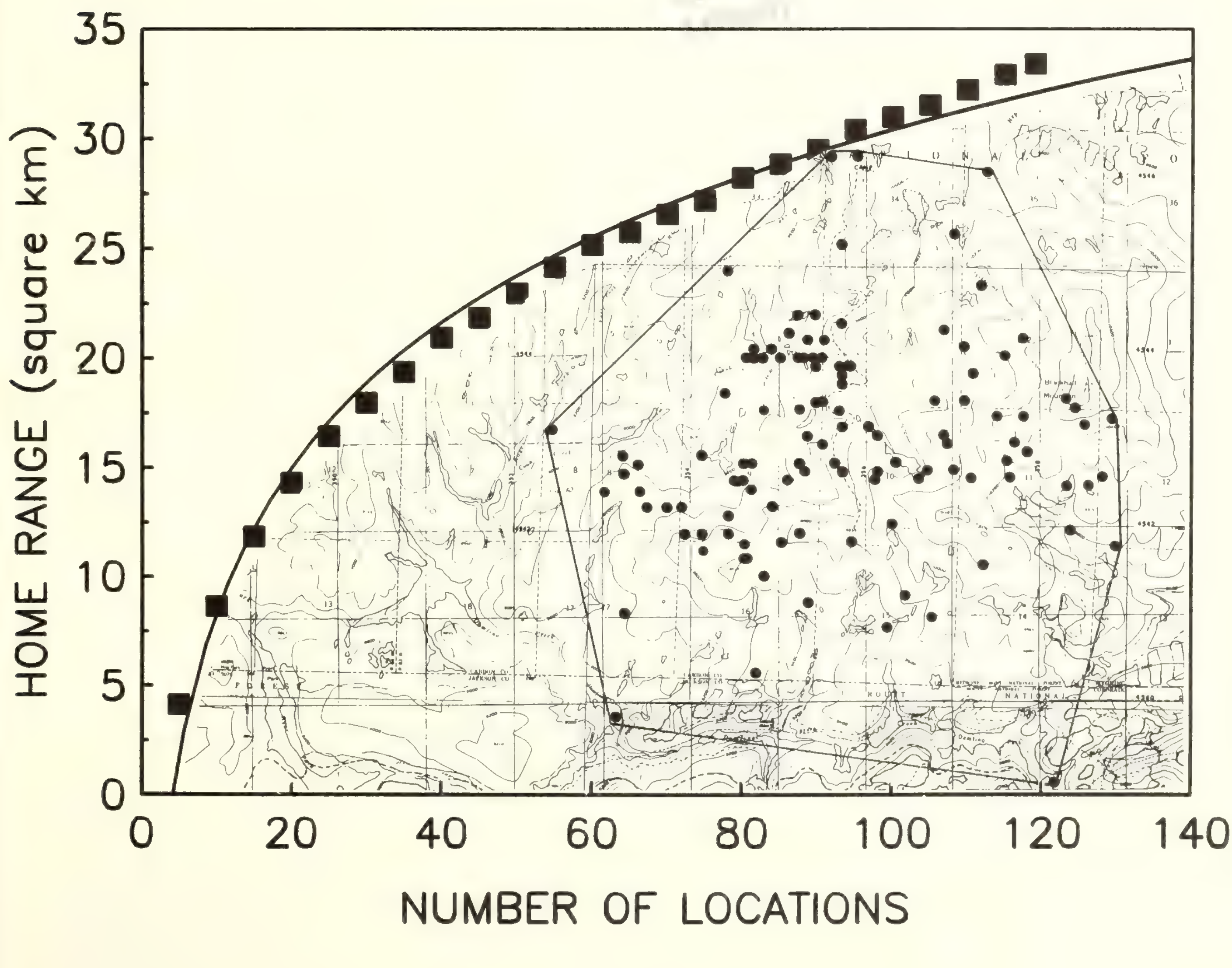
**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-165**

Bootstrap Estimation of Home Range Area: User's Guide to Program HOMERANG

Martin G. Raphael and Glen E. Brink



Abstract

Program HOMERANG estimates the home range area of an individual animal and uses bootstrapping to assess the influence of sample size. UTM coordinates of locations of sightings or captures are the "X-Y Cartesian points" used in computing the area of the largest polygon that will enclose all the locations. Sample runs are included.

USDA Forest Service
General Technical Report RM-165

September 1988

Bootstrap Estimation of Home Range Area: User's Guide to Program HOMERANG

Martin G. Raphael, Research Wildlife Biologist
and
Glen E. Brink, Computer Programmer Analyst
Rocky Mountain Forest and Range Experiment Station[1]

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Acknowledgments

The authors thank H. Allen, R. H. Barrett, and P. J. P. Gogan for comments on the manuscript and for evaluating the program. L. D. Van Dusen and R. M. King are also thanked for programming assistance and discussion of statistical techniques.

Bootstrap Estimation of Home Range Area: User's Guide to Program HOMERANG

Martin G. Raphael and Glen E. Brink

Program HOMERANG estimates the home range area of an individual animal and uses bootstrapping to assess the influence of sample size (Raphael, in prep.). Universal Transverse Mercator (UTM) coordinates of locations of sightings or captures are the "X-Y Cartesian points" used in computing the area of the largest polygon that will enclose all the locations. An index of home range size (Metzgar and Sheldon 1974) is also computed, using nonlinear regression to fit

Y = a * [1 – e**(-bX)]

where

X = number of locations
Y = home range size
a = regression parameter and index of home range size
b = regression parameter.

The program is written in FORTRAN 77, compiled by the Microsoft FORTRAN compiler (4.01), and runs on IBM PC compatible equipment.[2] It requires 150,000 available bytes of memory and space on a disk or diskette for input/output files. An online printer for displaying the results is recommended. The version in the root directory on the diskette requires a math coprocessor; if one is not present, the message "Floating point routines not loaded" will appear when the program is executed. A version of the program that does not require a math coprocessor is in the subdirectory NO87 on the distribution diskette.

Input is in two forms:

1. Data file. This file contains an identification number for each animal, the date of the sighting or capture, and the UTM coordinates. The file must be in ascending order by identification number and date.
2. Keyboard instructions at execution time, which establish the desired options for the run. (These instructions may be saved on a disk file for use in subsequent runs, thus avoiding repetitive keyboarding.)

Output is in three forms:

1. Screen or console monitor. The instructions and interactions with the user during the establishment of the run options are displayed first. Because the program requires infrequent observable interaction with external devices, "I'm still working" messages appear on the screen during lengthy bootstrapping iterations. Finally, the iterations of the nonlinear regression to calculate the index of home range size are also displayed on the screen.
2. Printer. The results of the bootstrapping for all sample sizes (in selected increments) from 3 to the actual number of locations are printed, along with the standard error and the 95% confidence interval. A summary of the home range size index computations is then printed at the foot of the output; it shows the index, its 95% confidence interval, the regression coefficients, and the predicted number of locations that would be required to achieve 95% of the index.
3. Disk file. An exact copy of the bootstrapping output displayed on the printer, but without headings or the summary of home range size index information, is filed on the disk for use as input to other software such as graphics packages.

Executing the Program

The discussion below contains the interactions of an actual run, with the program's communication in upper case, and the user's instructions and responses in lower case. Comments for the purpose of this guide are enclosed in brackets [ ], and are neither displayed by the program nor entered by the user:

homerang [The user initiates a run with this command.]

ESTIMATE OF HOME RANGE AREA 06-15-88 10:24:10 [The program responds with the date and time and asks for the name of the input file.]

INPUT FILE NAME?
marten-2.dat
[Both the input and output files names may contain path information and each is limited to 80 characters.]

[2]Use of trade or company names is for the benefit of the reader and does not imply endorsement or preferential treatment by the U.S. Department of Agriculture.

OUTPUT FILE NAME?
marten-2.out

IS AN ONLINE PRINTER AVAILABLE? (Y = YES) > n

NAME OF FILE TO RECEIVE "PRINTED" OUTOUT?
marten-2.prn

[It is recommended that an online printer be used. If not, respond "N" and the next prompt will request disk space.]

THE FOLLOWING DEFAULTS ARE IN EFFECT:

[The program displays the default options. If the defaults are acceptable, the user merely presses the enter key when asked. If revised defaults from an earlier run were saved on a disk file, that file may be read by typing "R" and responding to the prompts; the revised defaults will then be displayed and the user could introduce still further modifications. The example below changes all 9 options from the original set, but only for illustration. All options may be reset as many times as necessary to configure the desired run.]

```
1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION:  10
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  1
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  1000
4) ESTIMATE COMPUTED BY DATE: NO
5) RANDOM NUMBER GENERATOR SEEDS:  1794 26680
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  100
9) START REGRESSION WITH USER SPECIFIED VALUES?  N
```

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 1 [The 1 is the user's response.]

[If the user's data file contains many animals, or if the run is to be done by date (line 4), it is possible that there will be insufficient sightings to perform an area computation. Obviously, the minimum number of points required is 3, but the user may wish to limit the run to a more significant number of locations from which to draw the bootstrap samples. This does not limit the maximum number of points that will be considered for an animal; it merely excludes animals or dates that have an insufficient or an insignicant number of locations. In this case, the user responds below with "8", meaning that any animal (or date, if the run is being done by date) with fewer than eight locations would eliminated.]

ENTER THE MINIMUM NUMBER OF LOCATIONS FOR INCLUSION,
3 <= MINIMUM <= 500 > 8

[The program now displays again the entire set of options, including the revised number of locations. If necessary, line 1 could be changed again. The bold face in the display below is only for the purpose of this guide and is not part of the program.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8

```
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  1
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  1000
4) ESTIMATE COMPUTED BY DATE:  NO
5) RANDOM NUMBER GENERATOR SEEDS:  1794 26680
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
```

7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 2 [The 2 is the user's response.]

[The program will randomly draw samples of size 3, 4, 5, . . . N, from the set of N locations and compute the area for each sample. If N is large, the time required to complete the run may be prohibitive. The time for the run could be reduced by specifying either a larger initial sample size or a larger increment between sample sizes. Note that any reduction diminishes the number of points available to the regression and that the final sample size, which includes all N locations, is always calculated regardless of the pattern established by the increment.]

ENTER THE INITIAL SAMPLE SIZE TO DRAW > 20 [The 20 and the 2
ENTER THE INCREMENT OF SAMPLE SIZE BETWEEN DRAWS >2 are the user's responses.]
[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 1000
4) ESTIMATE COMPUTED BY DATE: NO
5) RANDOM NUMBER GENERATOR SEEDS: 1794 26680
6) INPUT FORMAT:

ANIMAL ID NUMBER	COL	11- 12	
MONTH		15- 16	
DAY		18- 19	
YEAR		21- 22	
UTM NORTH COORDINATE		28- 33	(DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE		40- 44	(DIGITS AFTER IMPLIED DECIMAL: 1)

7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 3 [The 3 is the user's response.]

[Bootstrapping requires that M samples be drawn for each sample size, and the mean of the M areas thus computed is the computed home range area. As M grows larger, the time required for a run will increase. The user can alter M by entering a 3 as shown above. In this example, the number of bootstrap iterations or the number of samples to be drawn is set to 200. Note that a larger M will result in a smaller standard error.]

ENTER THE NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN > 200
[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: NO
5) RANDOM NUMBER GENERATOR SEEDS: 1794 26680
6) INPUT FORMAT:

ANIMAL ID NUMBER	COL	11- 12	
MONTH		15- 16	
DAY		18- 19	
YEAR		21- 22	
UTM NORTH COORDINATE		28- 33	(DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE		40- 44	(DIGITS AFTER IMPLIED DECIMAL: 1)

7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 4 [The 4 is the user's response.]

[If the run is to perform the analysis by date, the user enters either "Y" or "y" without the quotes. When this option is selected, the data must be in order by date. The data can then be processed by time periods for each animal. The user may group the months into a minimum of 1 time period and a maximum of 12 time periods. As the user is prompted for the time period for each month, the period number is entered.]

IS THE ESTIMATE TO BE COMPUTED BY DATE? (Y = YES) > y [The user's data is ordered by date and is to be processed in 2 "seasons".]
PLEASE ENTER PERIOD FOR JAN (1-12) > 1
PLEASE ENTER PERIOD FOR FEB (1-12) > 1
PLEASE ENTER PERIOD FOR MAR (1-12) > 1
PLEASE ENTER PERIOD FOR APR (1-12) > 2
PLEASE ENTER PERIOD FOR MAY (1-12) > 2
PLEASE ENTER PERIOD FOR JUN (1-12) > 2
PLEASE ENTER PERIOD FOR JUL (1-12) > 2
PLEASE ENTER PERIOD FOR AUG (1-12) > 2
PLEASE ENTER PERIOD FOR SEP (1-12) > 2
PLEASE ENTER PERIOD FOR OCT (1-12) > 1
PLEASE ENTER PERIOD FOR NOV (1-12) > 1
PLEASE ENTER PERIOD FOR DEC (1-12) > 1
[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: YES
PERIOD/MONTH: 1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC
5) RANDOM NUMBER GENERATOR SEEDS: 1794 26680
6) INPUT FORMAT:
ANIMAL ID NUMBER COL 11- 12
MONTH 15- 16
DAY 18- 19
YEAR 21- 22
UTM NORTH COORDINATE 28- 33 (DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE 40- 44 (DIGITS AFTER IMPLIED DECIMAL: 1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 5 [The 5 is the user's response.]

[The program utilizes a good pseudo-random number generator (Thesen 1985) for the randomizing of the draws in bootstrapping. It requires two seeds, both of which must be integers between 1 and 32767 inclusive. The term "pseudo" is applied because if the same two seeds are used in successive runs, the same sequence of "random numbers" will be generated. The default seeds are a function of the date and time of the run, thus attempting to introduce some randomness even into starting of the generator. If, however, it is desired to replicate a previous run precisely, the user may enter the random number seeds that were used in that run.]

ENTER TWO RANDOM NUMBER GENERATOR SEEDS BETWEEN 1 AND 32767 INCLUSIVE
(SPACE BETWEEN THEM) > 17 19
[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: YES
PERIOD/MONTH: 1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC

5) RANDOM NUMBER GENERATOR SEEDS: 17 19
6) INPUT FORMAT:
ANIMAL ID NUMBER COL 11- 12
MONTH 15- 16
DAY 18- 19
YEAR 21- 22
UTM NORTH COORDINATE 28- 33 (DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE 40- 44 (DIGITS AFTER IMPLIED DECIMAL: 1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 6 [The 6 is the user's response.]

[If the user's input file named at the beginning of the interaction with the program is not in the default format, the user must specify the new format. The program will ask for the column numbers of each of the fields; the fields do not have to be in the same order as requested, as shown below when the user's date format is YY/MM/DD. The field width of the ID number, month, day, and year may not exceed 2 digits; for the UTM coordinates, the maximum field width is 9, including the decimal if it is explicitly entered into the data file.]

INPUT FORMAT: ENTER THE BEGINNING AND ENDING COLUMN NUMBERS (SPACE BETWEEN THEM).
ANIMAL ID NUMBER? > 1 2
MONTH? > 5 6
DAY? > 7 8
YEAR? > 3 4
UTM N? > 11 15

NUMBER OF DIGITS RIGHT OF IMPLIED DECIMAL POINT?
(IF THE DECIMAL IS ALREADY ENTERED IN EACH VALUE OR IF THERE IS NO NEED FOR AN IMPLIED DECIMAL, ENTER 0) > 1
UTM E? > 16 20

NUMBER OF DIGITS RIGHT OF IMPLIED DECIMAL POINT?
(IF THE DECIMAL IS ALREADY ENTERED IN EACH VALUE OR IF THERE IS NO NEED FOR AN IMPLIED DECIMAL, ENTER 0) > 1
[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: YES
PERIOD/MONTH: 1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC
5) RANDOM NUMBER GENERATOR SEEDS: 17 19
6) INPUT FORMAT:
ANIMAL ID NUMBER COL 1- 2
MONTH 5- 6
DAY 7- 8
YEAR 3- 4
UTM NORTH COORDINATE 11- 15 (DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE 16- 20 (DIGITS AFTER IMPLIED DECIMAL: 1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 7 [The 7 is the user's response.]

[The default "critical value" used in the computations between the standard error and the confidence interval is 2.0, but may be adjusted for different alpha levels or multiple regression comparisons. The value should depend on degrees of freedom, which depends on the size of the data set. The usual formula is df = $(n - p - 1)$ where n is the sample size (number of locations), and p is the number of regression parameters (2).]

ENTER "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.576

[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: YES
   PERIOD/MONTH: 1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
   1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC
5) RANDOM NUMBER GENERATOR SEEDS: 17 19
6) INPUT FORMAT:

ANIMAL ID NUMBER	COL	1- 2	
MONTH		5- 6	
DAY		7- 8	
YEAR		3- 4	
UTM NORTH COORDINATE		11- 15	(DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE		16- 20	(DIGITS AFTER IMPLIED DECIMAL: 1)

7) **"CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.6**
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 8 [The 8 is the user's response.]

[The regression usually is terminated after 100 attempts at convergence; the user may expand the number of attempts if it appears that success may be achieved by doing so. The computational time increase for 150 iterations, for example, would be minimal.]

ENTER MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 150

[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 200
4) ESTIMATE COMPUTED BY DATE: YES
   PERIOD/MONTH: 1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
   1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC
5) RANDOM NUMBER GENERATOR SEEDS: 17 19
6) INPUT FORMAT:

ANIMAL ID NUMBER	COL	1- 2	
MONTH		5- 6	
DAY		7- 8	
YEAR		3- 4	
UTM NORTH COORDINATE		11- 15	(DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE		16- 20	(DIGITS AFTER IMPLIED DECIMAL: 1)

7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.6
8) **MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 150**
9) START REGRESSION WITH USER SPECIFIED VALUES? N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 9 [The 9 is the user's response.]

[Occasionally, the regression's default initial parameters are such poor estimates that convergence cannot be achieved. The user may opt to specify initial estimates, as illustrated below. These estimates may be taken from values listed at the end of a previous run.]

START REGRESSION WITH USER SPECIFIED VALUES? (Y = YES): y
ENTER SPECIFIED VALUE FOR PARAMETER 1: 11.
ENTER SPECIFIED VALUE FOR PARAMETER 2: .055

[The program redisplays the options.]

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 8
2) INITIAL SAMPLE SIZE TO DRAW: 20
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2

```
3)  NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  200
4)  ESTIMATE COMPUTED BY DATE:  YES
    PERIOD/MONTH:  1/JAN 1/MAR 2/MAY 2/JUL 2/SEP 1/NOV
                   1/FEB 2/APR 2/JUN 2/AUG 1/OCT 1/DEC
5)  RANDOM NUMBER GENERATOR SEEDS:  17 19
6)  INPUT FORMAT:
    ANIMAL ID NUMBER          COL   1- 2
    MONTH                           5- 6
    DAY                             7- 8
    YEAR                            3- 4
    UTM NORTH COORDINATE           11- 15  (DIGITS AFTER IMPLIED DECIMAL:  1)
    UTM EAST COORDINATE            16- 20  (DIGITS AFTER IMPLIED DECIMAL:  1)
7)  "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.6
8)  MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  150
9)  START REGRESSION WITH USER SPECIFIED VALUES?  Y
       SPECIFIED VALUE, PARAMETER 1:   11.0000
       SPECIFIED VALUE, PARAMETER 2:  .550000E-01
TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER  >
```

[When the options are configured as desired, the user responds to the above prompt with nothing more than an ENTER or carriage return. It should be noted that any response other than 1 through 9, an R, a space (which is interpreted as an Enter in this case), or an Enter is considered an invalid response and the options are redisplayed. The user is then given the opportunity to save the revised defaults on a file for use in subsequent runs.]

```
DO YOU WANT TO SAVE THE ABOVE DEFAULTS ON A FILE FOR POSSIBLE USE ON ANOTHER RUN?
(Y = YES)  > y
SAVED DEFAULTS FILE NAME?  marten-2.sav
```

[The defaults are saved on the specified disk file and the program begins execution. At any point in the parameter specification or in the run itself, the user may interrupt with a Ctrl Break and before the next message appears on the screen, the run will be terminated; however, the information already written to the disk file will be lost to normal use or viewing and a DIR will show the file to be 0 bytes in length. The DOS command CHKDSK /F must be run to clear the disk of the lost chain generated by the interrupt or its space will never be available again to DOS, even after issuing the command ERASE filename.ext.]

Sample Input File

2	9/26/85	4545.8	353.1
2	9/30/85	4543.2	353.6
2	10/10/85	4544.8	355.8
2	10/14/85	4544.8	355.3
2	10/21/85	4544.5	354.2
2	10/28/85	4544.4	353.3
2	11/01/85	4545.6	354.0
2	11/04/85	4542.9	354.4
2	11/12/85	4544.1	354.6
2	11/15/85	4544.3	353.6
2	11/22/85	4544.8	353.1
2	11/26/85	4543.2	355.3
2	12/03/85	4541.9	355.2
2	12/06/85	4545.1	353.7
2	12/11/85	4544.2	353.8
2	12/21/85	4543.9	353.8
2	12/25/85	4543.6	352.5
2	12/29/85	4544.1	353.6
2	1/03/86	4543.6	356.3
2	1/07/86	4541.5	355.6
2	1/10/86	4543.2	355.3
2	1/12/86	4542.8	354.3
2	2/07/86	4544.0	355.1
2	2/21/86	4543.4	355.5
2	2/28/86	4544.8	356.3
2	3/07/86	4545.2	353.0
2	3/10/86	4545.1	353.7
2	3/16/86	4543.8	354.6
2	3/17/86	4543.5	355.7
2	3/21/86	4544.7	354.5
2	3/24/86	4544.7	353.8
2	3/30/86	4543.6	355.4
2	4/02/86	4545.1	356.0
2	4/05/86	4545.0	356.0
2	4/07/86	4544.7	355.3
2	4/14/86	4544.9	355.8
2	4/19/86	4545.2	355.5
2	4/22/86	4544.8	355.7
2	4/22/86	4544.6	356.2
2	4/25/86	4544.3	355.7
2	4/29/86	4544.6	355.7
2	5/02/86	4544.3	355.3
2	5/08/86	4544.3	355.7

Sample Run: Screen

```
ESTIMATE OF HOME RANGE AREA 06-20-88 16:24:43

INPUT FILE NAME? 0 OUTPUT FILE NAME? 0 IS AN ONLINE PRINTER AVAILABLE? (Y = YES) > y
THE FOLLOWING DEFAULTS ARE IN EFFECT:

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION:  10
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  1
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  1000
4) ESTIMATE COMPUTED BY DATE:  NO
5) RANDOM NUMBER GENERATOR SEEDS:  2304 20640
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  100
9) START REGRESSION WITH USER SPECIFIED VALUES?  N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER    > 2
ENTER THE INITIAL SAMPLE SIZE TO DRAW > 3
ENTER THE INCREMENT OF SAMPLE SIZE BETWEEN DRAWS > 2

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION:  10
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  1000
4) ESTIMATE COMPUTED BY DATE:  NO
5) RANDOM NUMBER GENERATOR SEEDS:  2304 20640
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  100
9) START REGRESSION WITH USER SPECIFIED VALUES?  N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 3
ENTER THE NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN > 20

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION:  10
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  20
4) ESTIMATE COMPUTED BY DATE:  NO
5) RANDOM NUMBER GENERATOR SEEDS:  2304 20640
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
```

```
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  100
9) START REGRESSION WITH USER SPECIFIED VALUES?  N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER > 5
ENTER TWO RANDOM NUMBER GENERATOR SEEDS BETWEEN 1 AND 32767 INCLUSIVE
   (SPACE BETWEEN THEM) > 77 1638

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION:  10
2) INITIAL SAMPLE SIZE TO DRAW:  3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS:  2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN:  20
4) ESTIMATE COMPUTED BY DATE:  NO
5) RANDOM NUMBER GENERATOR SEEDS:  77 1638
6) INPUT FORMAT:
   ANIMAL ID NUMBER          COL  11- 12
   MONTH                          15- 16
   DAY                            18- 19
   YEAR                           21- 22
   UTM NORTH COORDINATE           28- 33  (DIGITS AFTER IMPLIED DECIMAL:  1)
   UTM EAST COORDINATE            40- 44  (DIGITS AFTER IMPLIED DECIMAL:  1)
7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL:  2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE:  100
9) START REGRESSION WITH USER SPECIFIED VALUES?  N

TO CHANGE ANY OF THE ABOVE, TYPE THE LINE NUMBER AND PRESS ENTER.
TO READ DEFAULTS SAVED FROM AN EARLIER RUN, TYPE R AND PRESS ENTER.
IF ALL ARE ACCEPTABLE, PRESS ENTER >
DO YOU WANT TO SAVE THE ABOVE DEFAULTS ON A FILE FOR POSSIBLE USE ON ANOTHER RUN?
(Y = YES)    > n

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF  3 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:45

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF  5 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:46

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF  7 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:46

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF  9 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:47

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 11 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:48

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 13 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:50

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 15 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:51

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 17 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:53

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 19 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:55

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 21 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:24:58

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 23 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:25:00

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 25 FOR ID 2, 9/26/85 - 5/ 8/86
                              06-20-88 16:25:03
```

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 27 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:06

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 29 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:09

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 31 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:13

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 33 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:17

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 35 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:21

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 37 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:25

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 39 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:29

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 41 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:34

FROM 43 POINTS, DRAWING A SAMPLE SIZE OF 43 FOR ID 2, 9/26/85 – 5/ 8/86
06-20-88 16:25:39

NONLINEAR REGRESSION

ITERATION	RES SUM SQ	P(1)	P(2) . . .
0	4.4722	10.4449	.0629
1	3.8040	10.5114	.0631
2	3.0957	10.6056	.0633
3	2.6331	10.7083	.0635
4	2.4698	10.7864	.0634
5	2.4030	10.8332	.0628
6	2.3458	10.8807	.0617
7	2.3103	10.9578	.0602
8	2.2774	11.0695	.0585
9	2.1782	11.1899	.0576
10	2.1271	11.2593	.0576
11	2.1333	11.2580	.0573
12	2.1291	11.2571	.0574
13	2.1275	11.2565	.0575
14	2.1271	11.2562	.0575
15	2.1270	11.2609	.0575
16	2.1273	11.2642	.0576
17	2.1270	11.2644	.0576
18	2.1269	11.2645	.0575
19	2.1270	11.2624	.0575
20	2.1269	11.2623	.0575
21	2.1273	11.2636	.0576
22	2.1271	11.2638	.0576
23	2.1269	11.2639	.0575
24	2.1269	11.2640	.0575
25	2.1269	11.2627	.0575
26	2.1269	11.2626	.0575
27	2.1270	11.2633	.0576
28	2.1269	11.2634	.0575
29	2.1269	11.2635	.0575
30	2.1269	11.2635	.0575
31	2.1269	11.2628	.0575
32	2.1269	11.2628	.0575
33	2.1269	11.2631	.0575
34	2.1269	11.2632	.0575
35	2.1269	11.2632	.0575
36	2.1269	11.2633	.0575
37	2.1269	11.2629	.0575

NORMAL TERMINATION.
Stop – Program terminated.

Sample Run: Printer

ESTIMATE OF HOME RANGE AREA 06-20-88 16:24:43

INPUT FILE:
marten-2.dat

OUTPUT FILE:
marten-2.out

1) MINIMUM SAMPLE SIZE (NUMBER OF LOCATIONS) FOR INCLUSION: 10
2) INITIAL SAMPLE SIZE TO DRAW: 3
   INCREMENT OF SAMPLE SIZE BETWEEN DRAWS: 2
3) NUMBER OF BOOTSTRAP SAMPLES TO BE DRAWN: 20
4) ESTIMATE COMPUTED BY DATE: NO
5) RANDOM NUMBER GENERATOR SEEDS: 77 1638
6) INPUT FORMAT:

ANIMAL ID NUMBER	COL	11- 12	
MONTH		15- 16	
DAY		18- 19	
YEAR		21- 22	
UTM NORTH COORDINATE		28- 33	(DIGITS AFTER IMPLIED DECIMAL: 1)
UTM EAST COORDINATE		40- 44	(DIGITS AFTER IMPLIED DECIMAL: 1)

7) "CRITICAL VALUE" FOR COMPUTING CONFIDENCE INTERVAL: 2.0
8) MAXIMUM NUMBER OF REGRESSION ITERATIONS FOR CONVERGENCE: 100
9) START REGRESSION WITH USER SPECIFIED VALUES?

ESTIMATION OF HOME RANGE AREA WITH BOOTSTRAPPING 06-20-88 16:24:43

INPUT FILE:
marten-2.dat

OUTPUT FILE:
marten-2.out

ID	FROM – TO	NO. POINTS TOT	SAM	HOME RANGE AREA ESTIMATE	STD ERR	95% CONF. INT. X = NORMAL, Y = PERCENTILE (SEE NOTE BELOW)		
2	9/26/85 – 5/ 8/86	43	3	.87	.98	−1.09	<= X <=	2.83
						.05	<= Y <=	2.48
2	9/26/85 – 5/ 8/86	43	5	2.09	1.00	.10	<= X <=	4.09
						.68	<= Y <=	3.56
2	9/26/85 – 5/ 8/86	43	7	3.73	1.36	1.02	<= X <=	6.45
						1.86	<= Y <=	5.46
2	9/26/85 – 5/ 8/86	43	9	4.81	1.59	1.62	<= X <=	7.99
						2.62	<= Y <=	6.88
2	9/26/85 – 5/ 8/86	43	11	5.21	1.30	2.61	<= X <=	7.82
						2.85	<= Y <=	7.33
2	9/26/85 – 5/ 8/86	43	13	6.02	1.78	2.46	<= X <=	9.58
						3.47	<= Y <=	8.19
2	9/26/85 – 5/ 8/86	43	15	6.97	1.10	4.77	<= X <=	9.17
						5.40	<= Y <=	8.47
2	9/26/85 – 5/ 8/86	43	17	6.92	1.11	4.70	<= X <=	9.13
						4.50	<= Y <=	8.23
2	9/26/85 – 5/ 8/86	43	19	7.66	1.13	5.39	<= X <=	9.92
						5.97	<= Y <=	9.56
2	9/26/85 – 5/ 8/86	43	21	7.91	1.40	5.10	<= X <=	10.71
						5.62	<= Y <=	9.91

2	9/26/85 – 5/ 8/86	43	23	8.50	1.44	5.61 <= X <=	11.38
						5.92 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	25	8.61	1.22	6.17 <= X <=	11.06
						6.25 <= Y <=	10.02
2	9/26/85 – 5/ 8/86	43	27	8.90	1.15	6.60 <= X <=	11.20
						6.36 <= Y <=	10.34
2	9/26/85 – 5/ 8/86	43	29	9.31	.83	7.65 <= X <=	10.97
						7.52 <= Y <=	10.23
2	9/26/85 – 5/ 8/86	43	31	9.56	1.04	7.49 <= X <=	11.63
						7.33 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	33	9.21	1.10	7.01 <= X <=	11.40
						7.00 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	35	9.63	1.02	7.58 <= X <=	11.68
						7.56 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	37	9.56	.90	7.75 <= X <=	11.36
						7.71 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	39	10.17	.49	9.19 <= X <=	11.15
						8.88 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	41	10.11	.67	8.77 <= X <=	11.44
						8.26 <= Y <=	10.44
2	9/26/85 – 5/ 8/86	43	43	10.44	.00	10.44 <= X <=	10.44
						10.44 <= Y <=	10.44
HOME RANGE SIZE INDEX				11.26	.31	10.64 <= X <=	11.89

REGRESSION COEFFICIENTS:
A = 11.2629
B = .0575

AT 95% OF INDEX, SAMPLE SIZE = 52.1
HOME RANGE AREA = 10.70

NOTE: CONFIDENCE INTERVALS BASED ON
X) NORMAL DISTRIBUTION USING "CRITICAL VALUE"
Y) PERCENTILE METHOD WHICH EXCLUDES THE LOWER 2.5% AND UPPER 2.5% OF THE ESTIMATED AREAS COMPUTED ABOVE

NORMAL TERMINATION. 06-20-88 16:25:41

Sample Run: Disk File

(Note: Excess blanks deleted to facilitate documentation display.)

2	9/26/85 – 5/ 8/86	43	3	.87	.98	−1.09	2.83	.05	2.48
2	9/26/85 – 5/ 8/86	43	5	2.09	1.00	.10	4.09	.68	3.56
2	9/26/85 – 5/ 8/86	43	7	3.73	1.36	1.02	6.45	1.86	5.46
2	9/26/85 – 5/ 8/86	43	9	4.81	1.59	1.62	7.99	2.62	6.88
2	9/26/85 – 5/ 8/86	43	11	5.21	1.30	2.61	7.82	2.85	7.33
2	9/26/85 – 5/ 8/86	43	13	6.02	1.78	2.46	9.58	3.47	8.19
2	9/26/85 – 5/ 8/86	43	15	6.97	1.10	4.77	9.17	5.40	8.47
2	9/26/85 – 5/ 8/86	43	17	6.92	1.11	4.70	9.13	4.50	8.23
2	9/26/85 – 5/ 8/86	43	19	7.66	1.13	5.39	9.92	5.97	9.56
2	9/26/85 – 5/ 8/86	43	21	7.91	1.40	5.10	10.71	5.62	9.91
2	9/26/85 – 5/ 8/86	43	23	8.50	1.44	5.61	11.38	5.92	10.44
2	9/26/85 – 5/ 8/86	43	25	8.61	1.22	6.17	11.06	6.25	10.02
2	9/26/85 – 5/ 8/86	43	27	8.90	1.15	6.60	11.20	6.36	10.34
2	9/26/85 – 5/ 8/86	43	29	9.31	.83	7.65	10.97	7.52	10.23

2	9/26/85 – 5/ 8/86	43	31	9.56	1.04	7.49	11.63	7.33	10.44
2	9/26/85 – 5/ 8/86	43	33	9.21	1.10	7.01	11.40	7.00	10.44
2	9/26/85 – 5/ 8/86	43	35	9.63	1.02	7.58	11.68	7.56	10.44
2	9/26/85 – 5/ 8/86	43	37	9.56	.90	7.75	11.36	7.71	10.44
2	9/26/85 – 5/ 8/86	43	39	10.17	.49	9.19	11.15	8.88	10.44
2	9/26/85 – 5/ 8/86	43	41	10.11	.67	8.77	11.44	8.26	10.44
2	9/26/85 – 5/ 8/86	43	43	10.44	.00	10.44	10.44	10.44	10.44

Example of Nonconvergence Printout

ESTIMATION OF HOME RANGE AREA WITH BOOTSTRAPPING 01-26-88 12:57:35

INPUT FILE: noconvrg.dat
OUTPUT FILE: noconvrg.out

		NO. POINTS		HOME RANGE AREA		95% CONF. INT. X = NORMAL, Y = PERCENTILE (SEE NOTE BELOW)	
ID	FROM – TO	TOT	SAM	ESTIMATE	STD ERR		
2	9/26/85 – 11/15/85	10	3	.72	.81	–.90 <= X <=	2.34
						.03 <= Y <=	2.27
2	9/26/85 – 11/15/85	10	4	1.25	.66	–.07 <= X <=	2.56
						.15 <= Y <=	2.14
2	9/26/85 – 11/15/85	10	5	2.20	.73	.73 <= X <=	3.67
						1.01 <= Y <=	3.35
2	9/26/85 – 11/15/85	10	6	2.66	.82	1.02 <= X <=	4.30
						1.29 <= Y <=	3.88
2	9/26/85 – 11/15/85	10	7	3.10	.69	1.72 <= X <=	4.48
						1.66 <= Y <=	3.82
2	9/26/85 – 11/15/85	10	8	3.84	.66	2.51 <= X <=	5.17
						2.63 <= Y <=	4.50
2	9/26/85 – 11/15/85	10	9	4.07	.40	3.27 <= X <=	4.88
						3.53 <= Y <=	4.50
2	9/26/85 – 11/15/85	10	10	4.50	.00	4.50 <= X <=	4.50
						4.50 <= Y <=	4.50
HOME RANGE SIZE INDEX				8.33	9.06	–9.80 <= X <=	26.46

REGRESSION COEFFICIENTS:
A = 8.3314
B = .0651

AT 95% OF INDEX, SAMPLE SIZE = 46.0
HOME RANGE AREA = 7.91

NOTE: CONFIDENCE INTERVALS BASED ON
X) NORMAL DISTRIBUTION USING "CRITICAL VALUE"
Y) PERCENTILE METHOD, WHICH EXCLUDES THE LOWER 2.5% AND UPPER 2.5% OF THE ESTIMATED AREAS COMPUTED ABOVE

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                             *
* FAILURE TO CONVERGE AFTER 20 ITERATIONS.  RESULTS ARE SUSPECT.              *
*                                                                             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

NORMAL TERMINATION. 01–26–88 12:58:48

References

Metzgar, L. H.; Sheldon, A. L. 1974. An index of home range size. Journal of Wildlife Management 38: 547–551.

Raphael, Martin G. A bootstrap technique for comparing homerange areas. (In preparation)

Thesen, Arne. 1985. An efficient generator of uniformly distributed random variates between zero and one. Simulation 44: 1, 17–22.

Raphael, Martin G. and Glen E. Brink. 1988. Bootstrap estimation of home range area: user's guide to program HOMERANG. USDA Forest Service General Technical Report RM-165, 14 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Program HOMERANG estimates the home range area of an individual animal and uses bootstrapping to assess the influence of sample size. UTM coordinates of locations of sightings or captures are the "X-Y Cartesian points" used in computing the area of the largest polygon that will enclose all the locations. Sample runs are included.

Keywords: Bootstrap, home range, home range index, minimum convex polygon, nonlinear regression

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526